JOURNAL OF AGRICULTURAL RESEARCH

VOL. XXI WASHINGTON, D. C., JUNE 1, 1921 No. 5

EFFECT OF RATION ON THE DEVELOPMENT OF PIGS

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I. CHEMICAL COMPOSITION OF PIGS AS INFLUENCED BY THE CHARACTER OF THE RATION

In the year 1911 a series of experiments [1] was begun at the Kansas Agricultural Experiment Station to study the deficiencies of corn as an exclusive ration for young growing pigs. The material for this and the following sections has been selected from the mass of data obtained in these experiments. The influence of the character of the ration upon the development of pigs has been studied by a number of investigators.[2] Forbes (*3*) noted that the specific effects of corn alone are in general a retarded development of the protein and bony tissue and an overdevelopment of fatty tissue. In a later publication by the same author and associates (*4*) the statement is made that rations deficient in constituents needed for growth resulted in a restricted development.

Sanborn (*8, 9, 10*), one of the first investigators in this country to study the effect of corn on the development of pigs, noted that pigs receiving corn only were deficient in muscular development and were overfat. Pigs receiving a higher protein ration gained weight more rapidly and with a smaller amount of feed.

Henry (*5, p. 83*) noted that the corn-fed hogs had an excessive development of fat but an inferior development of muscular tissue.

Emmett and associates (*2*) fed three lots of four 51-pound pigs during a 174-day period a ration of ground corn, blood meal, and calcium phosphate. Lot 1 was fed 0.32 pound of digestible protein per day per 100 pounds live weight; lot 2, 0.7 pound of digestible protein; lot 3, 0.94 pound of digestible protein. The slaughter test made at the end of the experiment showed that pigs in lot 1 were not normally developed. The protein intake was on too low a plane. Pigs in lot 2 showed a normal development, and there was little difference between the pigs

[1] These experiments were originated by Dr. Henry Jackson Waters while he was president of the Kansas State Agricultural College and were prosecuted under his direction by the Departments of Animal Husbandry and Chemistry of the Kansas Agricultural Experiment Station.

[2] No attempt is here made at a complete review of the literature on this subject. Bibliographies relative to this subject are given in Bulletin 169 (*11*) [3], Illinois Agricultural Experiment Station.

[3] Reference is made by number (italic) to "Literature cited," p. 341.

in lots 2 and 3, showing that the larger amount of protein given lot 3 had but little apparent influence.

Continuing the studies on the three lots of pigs mentioned above with reference to the ash content of these pigs, the authors (*11*) found that variations in the amount of digestible protein consumed did not influence significantly the percentages of distribution of total and water-soluble ash. In further studies on these same lots of pigs, Joseph (7) reports that variations in the amounts of protein consumed by growing pigs do not seem to affect the nature of the nitrogenous material produced during growth. When the supply of body protein is deficient, either quantitatively or qualitatively, it seems that only the amount of body protein is affected, while the character of the body proteins formed in the tissues remains unchanged.

The experiments conducted at the Kansas Agricultural Experiment Station cover a wide range of feeds and extended over a period of six years. Each numbered experiment refers to a year's work. For this reason the data obtained in regard to the effect of the character of the ration on the chemical composition of pigs are large in amount and varied in character.

PLAN OF THE EXPERIMENTS

The general plan of these experiments was to feed one lot of young growing pigs on corn alone, another lot on corn and ash, and other lots on corn supplemented with feeds calculated to supply either the protein or ash deficiency in corn, or both such deficiencies. The feeds supplying this protein contained ash, except for two lots in experiment VI. Each lot of animals usually consisted of three pigs. The pigs in all the lots for any one year were of uniform age, size, and breeding. But, unfortunately, the age of the pigs was not the same in different experiments. All were Duroc-Jerseys. The pigs were fed in individual stalls, and the pens were so constructed that those in the different lots had no access to foreign material. The amount consumed by each pig was carefully controlled and recorded. There were six experiments in all, one each year. The first one was of preliminary nature, and no data from this experiment are used in this and following papers. The data are taken only from pigs on which slaughter tests were made.

DESCRIPTION OF SUPPLEMENTARY FEEDS USED

BONE ASH.—This was ordinary commercial bone ash.

SYNTHETIC ASH.—This mixture was prepared according to Mendel's formula, except that magnesium citrate was omitted and calcium carbonate added.

Calcium phosphate (tertiary)....	10 parts;	sodium citrate....	15 parts.
Potassium phosphate (secondary).	37 parts;	sodium tartrate...	8 parts.
Sodium chlorid.....	20 parts;	ferric citrate.....	2 parts.
Calcium carbonate.....	92 parts.		

BLACK BLOOD ALBUMEN.—This was a commercial product containing 80.75 per cent protein and 3.61 per cent ash.

MILK PROTEIN.—This contained both the casein from skim milk separated by precipitation with acetic acid and the milk albumin separated by acetic acid and heat. It contained practically all the protein of the milk.

MILK CASEIN AND MILK ALBUMIN were the same as above, except that they were kept separate and were fed to different lots. In experiment VI commercial buttermilk casein was used.

PROTEIN-FREE SKIM MILK was the filtrate obtained after the separation of the casein and the albumin. This contained, as an average of several analyses, 0.68 per cent ash, 0.34 per cent nitrogenous compounds ($N \times 6.25$), and 5.90 per cent sugar.

CORN GERM was a commercial product containing on the average 16.50 per cent protein, 5.64 per cent ash, 19.13 per cent ether extract.

THE STARCH used was ordinary commercial cornstarch.

THE ASH-FREE BLOOD PROTEIN was prepared from blood defibrinated and chilled at the packing house. When received at the laboratory it was diluted with four or five times its volume of distilled water, acidified with acetic acid, and heated to boiling with live steam. The coagulum was filtered on linen cloth suspended on a steam cheese vat. After draining, it was washed with a large volume of distilled water and again filtered on the linen cloth and then dried over electric plates in a current of air. When dry it was ground to pass a millimeter sieve. As thus prepared it contained 95.06 per cent protein, 1.09 per cent ash, 0.0126 per cent calcium, and 0.082 per cent phosphorus. This is designated as ash-free blood protein.

METHOD OF COMBINING FEEDS

Ash as a sole supplement to corn was fed in such amounts as to make 2 or 2.5 per cent of the ration. When ash was fed in addition to some protein-supplying feed in experiment VI it constituted 4 per cent of the ration. The protein-free skim milk obtained from 3 pounds of milk was fed for each pound of corn. This proportion is designated as 1 to 3. The casein obtained from 3 pounds of milk was fed for each pound of corn to lot 16 in experiment VI, lot 22 in experiment V, and an equivalent amount to lot 35 in experiment VI. These amounts are designated casein 1 to 3. Lot 36, experiment VI, was fed casein in half these amounts. The amount is designated casein 1 to 1½. Lot 37, experiment VI, was started with the same ratio as the lots mentioned above, 1 to 3, and then the amount of casein was gradually reduced so as to give a progressively wider nutritive ratio. This is designated as casein reducing. The corn, starch, casein, and ash fed lot 34, experiment VI, were combined in such proportions as to give the nutritive ratio of average

corn. The seventh day feeding means that on every seventh day milk protein or milk casein from 3 pounds of milk was fed for each pound of corn and on six days corn alone was fed. The ash-free blood protein was fed in such amounts as to give a nutritive ratio approximating 1 to 4.

The black blood albumen was fed in such amounts as to make a nutritive ratio very nearly 1 to 5. Alfalfa pasture was the sole feed of the pigs in two lots. One representative pig from each of the latter lots was slaughtered when taken off the alfalfa pasture. After being taken off the pasture the pigs were fed corn alone. Milk albumin from 3 pounds of milk for each pound of corn was fed to lot 17 in experiment IV. In experiment V, lot 26, the albumin was fed in such amounts as to furnish an amount of protein nearly equivalent to the casein in 3 pounds of milk for each pound of corn. The former is designated as small amounts and the latter as large amounts. The corn germ was fed in the proportion of 1 pound of germ to 2 pounds of corn. The corn was fed in the form of meal, and the supplementary feeds were mixed with this meal.

AMOUNTS CONSUMED

The amounts of the several chemical constituents in the various feeds consumed by the different pigs during these trials are given in Table I. It should be noted that the data refer to only one pig from each lot.

TABLE I.—*Pounds of nutrients from corn and supplementary feeds consumed by pigs during the experiments*

Experiment No.	Lot No.	Ration.	Dry matter.	Ash.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
II....	1	Corn.....	441.07	7.51	42.58	9.03	363.34	18.61
II....	2	....do.....	373.68	6.36	36.07	7.65	307.83	15.77
		Ash (bone).....	11.11	11.11	.....	.....	.....	.....
		Total.....	384.79	17.47	36.07	7.65	307.83	15.77
II....	3	Corn.....	1,097.75	18.70	105.97	22.49	904.27	46.32
		Black-blood albumen.	139.08	5.79	129.21	.....	.....	3.78
		Total.....	1,236.83	24.49	235.48	22.49	904.27	50.10
II....	4	Corn.....	1,224.41	20.85	118.20	25.08	1,008.61	51.67
		Black-blood albumen.	152.75	6.35	142.25	.....	.....	4.15
		Ash (bone).....	47.62	47.62	.....	.....	.....	.....
		Total.....	1,424.78	74.82	260.45	25.08	1,008.61	55.82
III...	6	Corn.....	206.73	3.47	22.47	5.10	165.94	9.75
III...	7	....do.....	132.59	2.22	14.41	3.27	106.44	6.25
		Ash (synthetic).....	2.99	2.99	.....	.....	.....	.....
		Total.....	135.58	5.21	14.41	3.27	106.44	6.25

TABLE I.—*Pounds of nutrients from corn and supplementary feeds consumed by pigs during the experiments*—Continued

Experiment No.	Lot No.	Ration.	Dry matter.	Ash.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
III...	8	Corn	77.48	1.30	8.42	1.91	62.20	3.65
		Protein-free skim milk 1 to 3.	18.43	1.70	.85	.....	15.88	.....
		Total	95.91	3.00	9.27	1.91	78.08	3.65
III...	9	Corn	832.85	13.97	90.54	20.54	668.50	39.30
		Milk protein 1 to 3	98.95	6.33	89.39	.....	.....	3.23
		Total	931.80	20.30	179.93	20.54	668.50	42.53
IV...	13	Corn	383.45	8.60	41.88	9.24	310.93	12.80
IV...	14	....do	290.41	6.51	31.72	7.00	235.49	9.69
		Ash (synthetic)	6.42	6.42	.....	.....	.....	.....
		Total	296.83	12.93	31.72	7.00	235.49	9.69
IV...	15	Corn	340.37	7.63	37.17	8.20	276.01	11.36
		Protein-free skim milk 1 to 3.	65.81	6.43	3.24	.....	56.14	.....
		Total	406.18	14.06	40.41	8.20	332.15	11.36
IV...	16	Corn	775.04	17.39	84.65	18.67	628.46	25.87
		Casein 1 to 3	71.77	3.27	66.65	.....	.....	1.85
		Total	846.81	20.66	151.30	18.67	628.46	27.72
IV...	17	Corn	540.57	12.13	59.04	13.02	438.34	18.04
		Milk albumin (small amounts).	8.06	.71	6.71	.....	.....	.64
		Total	548.63	12.84	65.75	13.02	438.34	18.68
IV...	18	Corn	609.77	13.68	66.60	14.69	494.45	20.35
		Milk protein 1 to 3, every seventh day.	8.66	.43	8.00	.....	.....	.23
		Total	618.43	14.11	74.60	14.69	494.45	20.58
V....	21	Corn	239.47	3.97	27.25	5.13	193.19	9.93
V....	22	....do	581.25	9.47	65.72	12.42	469.65	23.99
		Milk casein 1 to 3	62.56	2.73	50.72	.....	7.91	1.20
		Total	643.81	12.20	116.44	12.42	477.56	25.19
V....	23	Corn	273.76	4.51	31.07	5.85	220.99	11.34
		Corn germ	150.34	6.97	21.47	8.66	95.38	17.86
		Total	424.10	11.48	52.54	14.51	316.37	29.20
V....	26	Corn	679.83	11.15	77.04	14.54	548.99	28.11
		Milk albumin (large amounts).	66.16	7.91	46.32	.....	8.38	3.55
		Total	745.99	19.06	123.36	14.54	557.37	31.66

TABLE I.—*Pounds of nutrients from corn and supplementary feeds consumed by pigs during the experiments*—Continued

Experiment No.	Lot No.	Ration.	Dry matter.	Ash.	Protein.	Crude fiber.	Nitrogen-free extract.	Ether extract.
V....	29	Corn	485.75	8.01	55.16	10.39	392.07	20.12
		Milk casein 1 to 3, every seventh day.	6.80	.30	5.61	.....	.76	.13
		Total	492.55	8.31	60.77	10.39	392.83	20.25
III–V	(1)	Corn	1,849.70	33.45	203.73	49.95	1,487.36	75.21
		Ash (synthetic)	40.54	40.54	.....	.....	.....	.....
		Total	1,890.24	73.99	203.73	49.95	1,487.36	75.21
III–V	(1)	Corn	1,723.43	31.32	190.75	38.34	1,392.60	70.42
		Protein-free skim milk 1 to 3.	332.43	31.69	16.03	.....	284.71	.....
		Total	2,055.86	63.01	206.78	38.34	1,677.31	70.42
VI...	30	Corn	118.61	1.79	12.99	2.41	95.95	5.47
VI...	31	....do	112.83	1.70	12.36	2.29	91.28	5.20
		Ash (synthetic)	3.15	3.15	.....	.....	.....	.....
		Total	115.98	4.85	12.36	2.29	91.28	5.20
VI...	32	Corn	203.32	3.06	22.27	4.13	164.49	9.37
		Ash-free blood protein.	23.90	.27	23.61	.....	.....	.02
		Total	227.22	3.33	45.88	4.13	164.49	9.39
VI..	33	Corn	358.77	5.41	39.29	7.29	290.24	16.54
		Ash-free blood protein.	42.18	.48	41.66	.....	.....	.04
		Ash (synthetic)	17.78	17.78	.....	.....	.....	.....
		Total	418.73	23.67	80.95	7.29	290.24	16.58
VI...	34	Corn	226.87	3.42	24.84	4.61	183.54	10.46
		Starch	190.71	2.21	.76	.....	187.59	.15
		Casein	27.36	.80	21.85	.....	1.47	3.24
		Ash (synthetic)	12.56	12.56	.....	.....	.....	.....
		Total	457.50	18.99	47.45	4.61	372.60	13.85
VI....	35	Corn	432.40	6.52	47.35	8.78	349.81	19.94
		Casein 1 to 3	101.03	2.94	80.70	.....	5.42	11.97
		Ash (synthetic)	14.87	14.87	.....	.....	.....	.....
		Total	548.30	24.33	128.05	8.78	355.23	31.91
VI...	36	Corn	466.03	7.02	51.03	9.47	377.02	21.49
		Casein 1 to 1½	26.06	.76	20.81	.....	1.40	3.09
		Ash (synthetic)	13.73	13.73	.....	.....	.....	.....
		Total	505.82	21.51	71.84	9.47	378.42	24.58
VI...	37	Corn	484.59	7.30	53.07	9.85	392.03	22.34
		Casein reducing	32.35	.94	25.84	.....	1.74	3.83
		Ash (synthetic)	14.28	14.28	.....	.....	.....	.....
		Total	531.22	22.52	78.91	9.85	393.77	26.17

[1] Continuation hog.

SLAUGHTER TESTS

One or two representative pigs were slaughtered and analyzed at the beginning of the trial, it being assumed that the rest of the pigs used in the trial had the same average composition as these pigs which were designated as control pigs. At the close of the trial one representative pig from each of several lots was slaughtered. In this and the following sections only the data from pigs slaughtered are used. The following are the most important data which were obtained at the time of slaughter:

Live weight.
Weight of blood as obtained.
Weight of dressed carcass.
Weight of the several internal organs.
Weight of stomach, intestines, and bladder before and after removing contents.
Weight of fatty tissues, lean tissue, skin, and bones.
Chemical composition of the various portions into which the animals were divided.

After separation, these parts or portions were ground to a pulp by passing several times through a power sausage mill. The bones were first passed through a bone cutter. In the first three experiments six samples from each pig were prepared and analyzed—namely, blood, internal organs, lean tissue, fat tissue, skin, and bones. In experiments V and VI these were combined so as to make but two samples, soft tissue and bones. Since the weight of these several portions and the percentages of moisture, ash, protein, and ether extract or fat were known,[1] it was possible to calculate the pounds of these constituents present. The percentage composition was then calculated by dividing the total pounds of each of the several constituents by the live or empty weight, as the case might be. This latter refers to the weight of the animal less the weight of the contents of the stomach, intestines, and bladder. In this paper the percentages on the basis of empty weight are used.

PERCENTAGE COMPOSITION OF THE CONTROL PIGS

The percentages of moisture, ash, protein, and ether extract or fat, as well as the age and empty weight of the control pigs slaughtered in these five experiments, are given in Table II. In experiments II and III there were two control pigs slaughtered and analyzed, and the figures given are the averages of these. Unfortunately, the ages of the pigs in the different experiments are not the same. The fact that the pigs were started at an earlier age in some experiments than in others no doubt had an influence on the results.

[1] As this ether extract was nearly pure fat, this term will be used.

TABLE II.—*Chemical composition of control pigs*

Experiment No.	Age of pigs.	Empty weight.	Moisture.	Ash.	Protein.	Ether extract.
	Months.	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
II	4½	50. 38	50. 38	3. 30	13. 03	27. 39
III	3½	37. 65	49. 03	2. 79	11. 98	29. 00
IV	4	40. 97	55. 67	5. 92	16. 35	25. 30
V	2	34. 63	60. 50	3. 06	15. 42	14. 87
VI	2¼	21. 72	57. 18	2. 81	13. 44	15. 15

From experiment III, one pig from the lot fed corn and synthetic ash and one from the lot fed corn and protein-free skim milk were continued on these feeds until they were nearly 3 years old. At the time the pigs from experiment V were slaughtered these two were included in the test. These two pigs are indicated by the name of the ration and the numerals III–V. For convenience these two are called continuation hogs, since they were continued from experiment III to the end of experiment V.

CHEMICAL COMPOSITION OF REPRESENTATIVE PIGS

The figures for percentages of moisture, ash, protein, and ether extract in representative pigs from different lots in these experiments are found in Table III. These figures were calculated on the basis of empty weight. For purposes of study these figures are arranged in the order of increasing empty weights, beginning with the smallest.

MOISTURE CONTENT

The figures for moisture percentages are plotted in figure 1, using the empty weights as ordinates and the percentages of moisture as abscissas. The roman numerals throughout the legends refer to the different experiments. On the whole, the percentage of moisture decreases as the size increases. This curve shows that these pigs can be divided roughly into three classes: (1) Below 100 pounds, (2) between 100 and 300 pounds, and (3) above 300 pounds. In pigs below 100 pounds the variations are irregular in the extreme, and all the pigs in this class had deficient rations. In the second class the variation is somewhat more regular, and there is no distinct tendency to decrease in percentage of moisture with increasing size. The pigs weighing more than 100 pounds and less than 300 pounds, which were fed a ration supplying both protein and ash in addition to corn, have a tendency to carry a higher moisture content than those which were fed either protein or ash alone as a supplement. Above 300 pounds the curve shows distinctly that the tendency is to a decrease in moisture as the size increases. Size is the predominating factor when the ration produced an animal weighing between 300 and 400 pounds. This is due to the accumulation of fat, as will be shown later.

TABLE III.—*Chemical composition of representative pigs slaughtered at the end of each experiment*

[Arranged in the order of increasing weights of pigs]

Experiment No.	Lot No.	Ration.	Age of pig at start.	Empty weight.	Moisture.	Ash.	Protein.	Ether extract.
			Months.	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
III	8	Corn and protein-free skim milk	3½	28.06	59.49	4.34	15.20	15.02
VI	30	Corn alone	2¼	28.60	65.36	3.81	14.30	11.40
VI	31	Corn and synthetic ash	2¼	34.37	58.11	2.59	12.08	15.51
III	7	do	3½	45.02	46.01	3.44	11.28	23.65
IV		Alfalfa pasture	4	51.25	60.35	4.53	19.39	15.43
V	21	Corn alone	2	62.71	44.70	2.22	11.48	40.50
III	6	do	3½	63.28	39.93	2.69	11.44	34.46
III		Alfalfa pasture	3½	63.60	66.68	3.96	16.41	5.27
VI	32	Corn and ash-free blood protein	2¼	72.18	49.65	2.09	14.11	37.26
IV	14	Corn and synthetic ash	4	86.40	45.03	2.88	12.08	40.83
IV	13	Corn alone	4	105.25	40.82	2.57	10.94	47.16
II	2	Corn and bone ash	4½	122.80	36.85	2.71	11.25	48.48
IV	15	Corn and protein-free skim milk	4	127.45	38.10	2.27	9.59	50.95
V	29	Corn and casein every seventh day	2	139.84	37.69	1.63	10.45	48.78
V	23	Corn and corn germ	2	140.44	45.88	1.83	12.03	38.37
II	1	Corn alone	4½	141.49	34.83	2.16	9.88	49.91
VI	33	Corn, ash-free blood protein, and synthetic ash	2¼	156.86	46.91	2.63	13.02	40.44
VI	34	Corn, starch, casein, and synthetic ash	2¼	159.35	43.74	2.43	12.20	38.55
IV	17	Corn and milk albumin (small amounts)	4	180.99	36.61	1.75	10.95	52.31
VI	37	Corn, casein reducing, and synthetic ash	2¼	192.20	44.86	2.61	12.30	44.20
VI	36	Corn, casein 1 to 1¼, and synthetic ash	2¼	195.66	41.18	2.46	12.03	40.72
VI	35	Corn, casein 1 to 3, and synthetic ash	2¼	199.71	44.78	2.74	12.69	40.84
IV	18	Corn and milk protein every seventh day	4	209.95	36.49	1.96	10.81	51.21
V	22	Corn and casein 1 to 3	2	211.22	39.33	2.10	12.65	46.71
V	26	Corn and milk albumin (large amounts)	2	245.15	37.39	2.02	11.33	46.30
IV	16	Corn and casein 1 to 3	4	282.58	39.67	1.92	9.28	47.63
III	9	Corn and milk protein	3½	318.93	32.68	1.60	10.37	52.42
III–V	Continuation hogs.	Corn and synthetic ash	3½	364.52	30.92	1.71	8.32	56.75
III–V	do	Corn and protein-free skim milk	3½	366.42	33.23	2.05	9.87	53.46
II	3	Corn and black blood albumen	4½	378.20	27.66	1.47	9.22	59.08
II	4	Corn, black blood albumen, and bone ash	4½	389.26	25.66	1.76	8.51	61.53

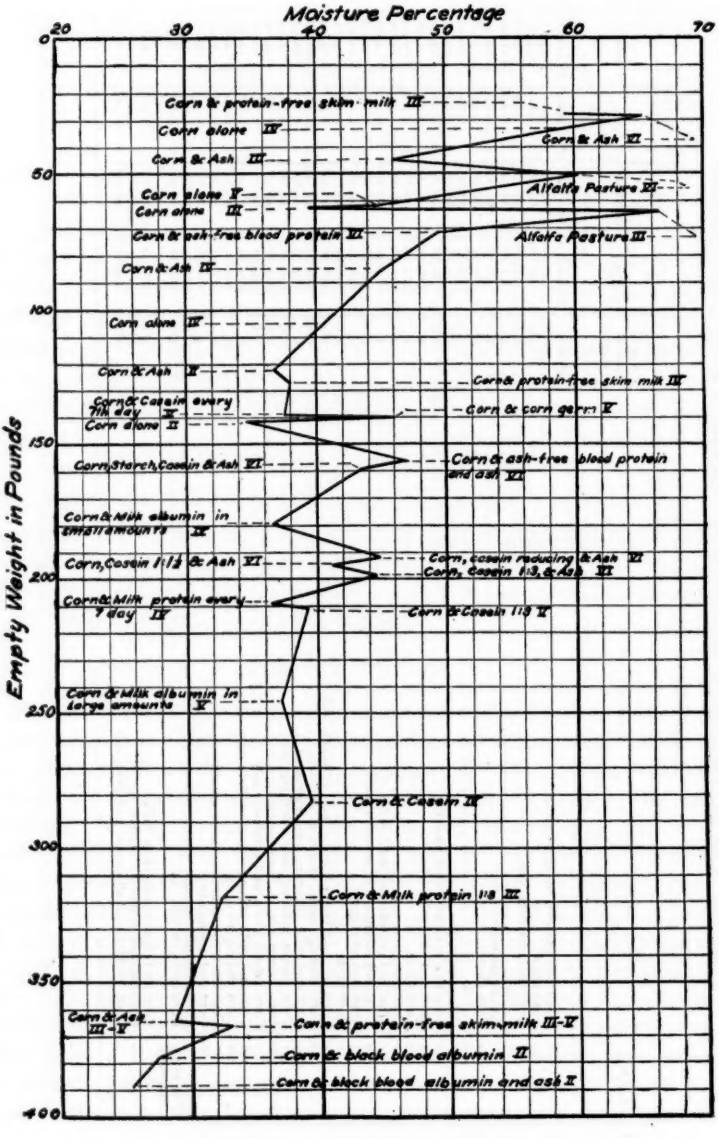

FIG. 1.—Graph showing the relation between percentage of moisture and empty weight.

FAT CONTENT

The figures for the percentages of fat are plotted in figure 2 in a manner similar to that used in figure 1. As in the case of the moisture percentages, the pigs below 100 pounds show extreme variation. Between 100 pounds and 250 pounds the variations show no distinct tendency to

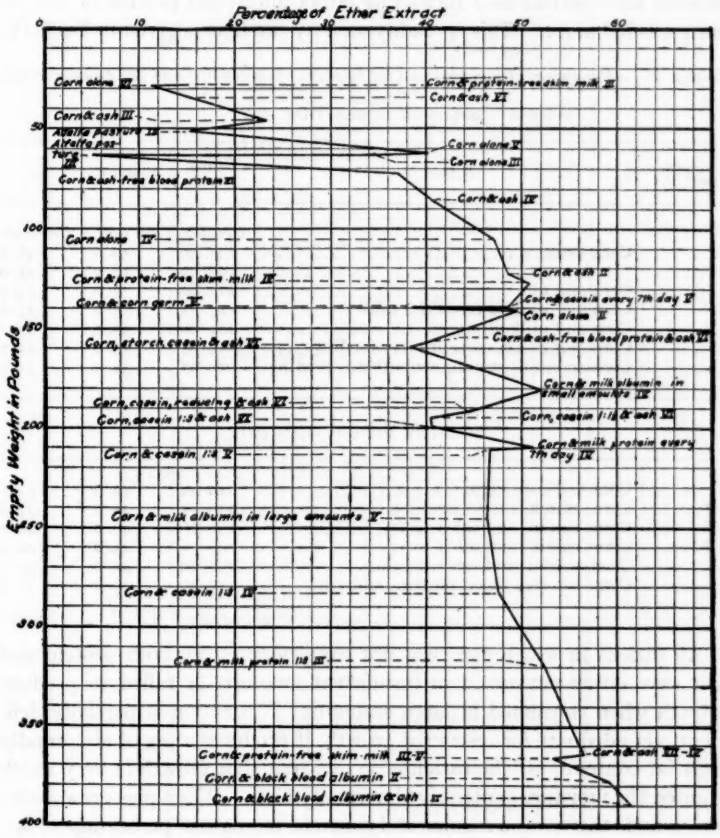

FIG. 2.—Graph showing the relation between percentage of fat (ether extract) and empty weight.

increase or decrease. Above 250 pounds the tendency to increase in fat content is pronounced.

COMPARISON OF THE PERCENTAGE OF MOISTURE AND FAT

The pigs which have a high moisture content have a low fat content. A study of the figures in Table III and the graphs in figures 1 and 2 will show that in all pigs whose weight is below 100 pounds the percentage of moisture is higher than the percentage of fat. In all pigs whose

weight is above 225 pounds the percentage of fat is higher than the percentage of moisture. Between these two limits the variation is irregular. If this irregularity is studied further it will be found that wherever the moisture content is higher than the fat content corn has been supplemented by both additional protein and ash. When the fat content is higher than the moisture content the corn has been supplemented only by one feed furnishing either additional protein or ash, or corn was fed alone. This is readily seen by the figures given in Table IV.

TABLE IV.—*Percentage of moisture and fat in pigs of between 100 and 225 pounds weight*

MOISTURE LOWER THAN FAT

Experiment No.	Ration.	Empty weight.	Moisture.	Fat.
		Pounds.	*Per cent.*	*Per cent.*
II	Corn alone	141. 50	33. 0	47. 0
IV	do	105. 25	38. 0	44. 0
II	Corn and ash	122. 80	35. 0	45. 0
IV	Corn and protein-free skim milk	127. 45	35. 0	47. 0
IV	Corn and milk albumin	181. 00	33. 0	47. 0
V	Corn and casein, seventh day feeding	139. 84	33. 0	43. 0
IV	Corn and milk protein, seventh day feeding	209. 95	34. 0	51. 0

MOISTURE HIGHER THAN FAT

V	Corn and corn germ	140. 44	40. 0	33. 0
VI	Corn, starch, casein, and ash	159. 35	42. 0	37. 0
VI	Corn, casein, and ash 1 to 1½	195. 66	40. 0	40. 0
VI	Corn, casein, and ash 1 to 3	199. 71	43. 0	40. 0
VI	Corn, casein, and ash widening	192. 20	42. 0	41. 0
VI	Corn, ash-free blood protein, and ash	156. 86	46. 0	39. 0

All rations in which corn was not supplemented by both protein and ash were either consumed in insufficient amounts or failed to produce growth when consumed in large amounts. If a ration is partially deficient, yet adequate for restricted growth, it produces a pig of abnormally high fat content. If the ration is so deficient that growth is very much stunted the moisture content is abnormally high. When pigs grew above 200 pounds there was a regular and constant increase in percentage of fat.

ASH CONTENT

The figures for ash percentages on the basis of empty weight are plotted in figure 3. In pigs weighing less than 80 pounds the variation is very irregular. The two pigs fed on alfalfa pasture and the one fed corn and protein-free skim milk had the highest percentage of ash. Among the pigs which weighed over 80 pounds and less than 210 pounds those fed corn and corn germ, corn and casein every seventh day, and corn and milk albumin in small amounts had the lowest percentage of ash. While

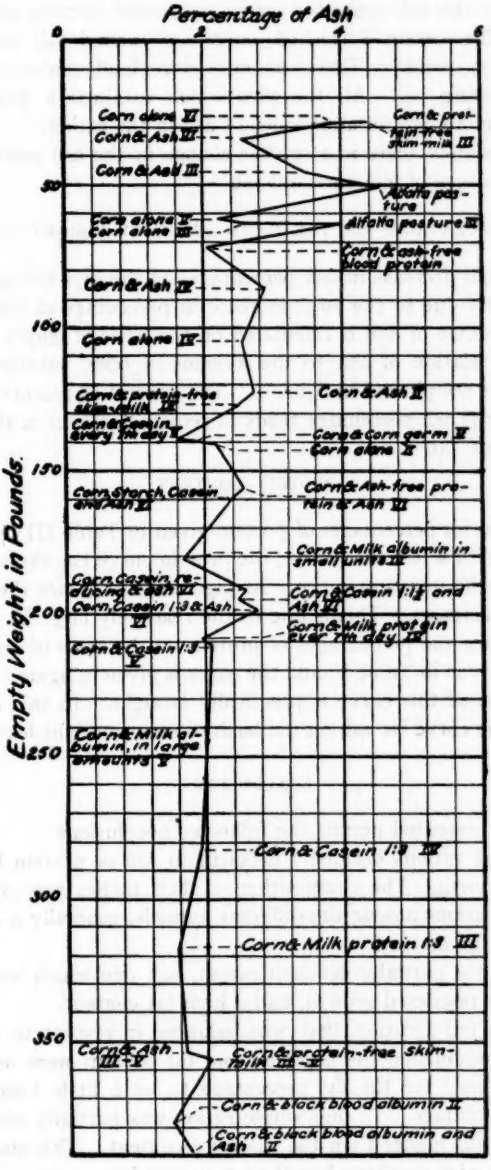
Percentage of Ash
0
2
4
6
Empty Weight in Pounds.
50
100
150
200
250
300
350
Corn alone VI
Corn & Ash VI
Corn & Ash III
Corn & prot-ein-free skim-milk III
Alfalfa pas-ture
Corn alone IV
Corn alone III
Alfalfa pasture III
Corn & ash-free blood protein
Corn & Ash IV
Corn alone IV
Corn & protein-free skim-milk IV
Corn & Ash II
Corn & Casein every 7th day V
Corn & Corn germ II
Corn alone II
Corn, Starch, Casein and Ash V
Corn & Ash-free pro-tein & Ash VI
Corn & Milk albumin in small units II
Corn, Casein, re-duced & Ash VI
Corn, Casein 1:3 & Ash VI
Corn & Casein 1:1½ and Ash VI
Corn & Milk protein every 7th day IV
Corn & Casein 1:3 V
Corn & Milk al-bumin, in large amounts I
Corn & Casein 1:3 III
Corn & Milk protein 1:3 III
Corn & Ash III - I
Corn & protein-free skim-milk III - II
Corn & black blood albumin II
Corn & black blood albumin and Ash II

FIG. 3.—Graph showing the relation between percentage of ash and empty weight.

the corn germ supplied 6.97 pounds of ash in addition to that present in the corn, yet this ash contained only 0.03 pound calcium, an inadequate amount. The casein furnished only 0.36 pound ash and the milk albumin 0.71 pound. These amounts were inadequate for the needs of the growing pig. All the pigs which attained a growth of 210 pounds or more had an abundance of ash in the ration.

Proportionately there is a smaller change in the ash percentage than in the percentage of moisture and fat.

ASH PERCENTAGES ON THE BASIS OF EMPTY WEIGHT, LESS FAT

The gradual decrease in ash percentages as the pigs increase in size is almost wholly due to the large increase in percentage of fat. In Table V the percentage of ash is calculated on the basis of empty weight less fat, or the relation of ash to the amount of body substance less fat. These results are plotted in figure 4. The general direction of this curve shows that the ash percentage tends to remain constant in the tissues of the body not fat.

PROTEIN CONTENT

The figures for percentages of protein given in Table III are plotted in figure 5. With a few exceptions, the protein curve has the same general direction as the moisture curve. As pigs increase in size the percentage of protein decreases. This is due to the relatively large increase of fat. The figures for the percentages of protein on the basis of empty weight less fat are given in Table V, and the curve is given in figure 6. The general direction of this curve is practically straight. In this respect it is similar to the curve for ash on the basis of empty weight less fat.

CONCLUSIONS

The data presented permit the following conclusions:

1. Pigs fed rations decidedly deficient in ash or protein had a very restricted growth. The composition of their bodies was characterized by wide variations among the different animals, generally a low fat and a high moisture content.

2. Pigs fed a partially deficient ration, but one which was sufficient to produce a restricted growth, had a high fat content.

3. In pigs fed a ration that was balanced in respect to the protein and ash requirements, the moisture and fat content were nearly equal, with a tendency for the fat percentage to be a little lower than the moisture percentage. In pigs whose ration was partially restricted, the fat content was higher than the moisture content. This statement applies only to pigs weighing less than 225 pounds.

TABLE V.—*Percentage of ash and protein in pigs, calculated on the basis of empty weight less fat*

[Arranged in order of increasing empty weight less fat]

Experiment No.	Lot No.	Ration.	Empty weight.	Weight of fat.	Empty weight less fat.	Weight of ash.	Weight of protein.	Percentage of ash in empty weight less fat.	Percentage of protein in empty weight less fat.
			Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*		
III	8	Corn and protein-free skim milk	28.06	4.22	23.84	1.22	4.27	5.12	17.91
VI	30	Corn alone	28.60	3.26	25.34	1.09	4.09	4.30	16.14
VI	31	Corn and synthetic ash	34.37	5.33	29.04	.89	4.15	3.07	14.29
III	7	do	45.62	10.79	34.83	1.56	5.14	4.48	14.76
V	21	Corn alone	62.71	25.40	37.31	1.39	7.20	3.73	19.30
III	6	do	63.28	21.80	41.48	.58	7.22	1.40	17.40
IV		Alfalfa pasture	51.25	9.26	41.99	2.72	11.64	6.48	27.73
VI	32	Corn and ash-free blood protein	72.18	26.91	45.27	1.51	10.19	3.34	22.51
IV	14	Corn and synthetic ash	86.40	34.99	51.41	2.47	10.35	4.80	20.13
IV	13	Corn alone	105.25	48.91	56.34	2.67	11.34	4.74	20.12
III		Alfalfa pasture	63.60	3.35	60.25	2.52	10.44	4.18	17.33
IV	15	Corn and protein-free skim milk	127.45	64.35	63.10	2.87	12.11	4.55	19.19
II	2	Corn and bone ash	122.80	54.48	68.32	3.06	12.67	4.48	18.54
V	29	Corn and casein every seventh day	139.84	68.21	71.63	2.28	14.61	3.18	20.40
II	1	Corn alone	141.49	64.71	76.78	2.79	12.81	3.63	16.68
V	23	Corn and corn germ	140.44	53.89	86.55	2.57	16.90	2.97	19.52
IV	17	Corn and albumin (small amounts)	180.99	93.17	87.82	3.12	19.50	3.55	22.19
VI	33	Corn, ash-free blood protein, and synthetic ash	156.86	63.43	93.43	4.11	20.43	4.40	21.86
IV	18	Corn and milk protein every seventh day	209.95	113.02	96.93	4.09	22.59	4.22	23.29
VI	34	Corn, starch, casein, and synthetic ash	159.35	61.44	97.91	3.89	19.45	3.97	19.86
VI	37	Corn, casein reducing, and synthetic ash	192.20	85.55	106.65	5.01	23.64	4.70	22.16
V	22	Corn and casein 1 to 3	211.22	98.67	112.55	4.43	26.73	3.93	23.74
VI	36	Corn, casein 1 to 1½, and synthetic ash	195.66	79.68	115.98	4.82	23.54	4.16	20.30
VI	35	Corn, casein 1 to 3, and synthetic ash	199.71	81.56	118.15	5.47	25.33	4.63	21.44
V	26	Corn and albumin (large amounts)	245.15	113.53	131.62	4.96	27.78	3.77	21.11
IV	16	Corn and casein 1 to 3	282.58	136.62	145.96	5.52	26.63	3.76	18.18
III	9	Corn and milk protein	318.93	167.22	151.71	5.09	33.08	3.36	21.81
III–V	Continuation hog.	Corn and synthetic ash	364.52	206.85	157.67	6.24	30.34	3.96	19.24
II	4	Corn, black-blood albumen, and bone ash	389.26	230.64	158.62	6.59	31.89	4.15	20.11
II	3	Corn and black-blood albumen	378.20	215.17	163.03	5.36	33.59	3.29	20.60
III–V	Continuation hog.	Corn and protein-free skim milk	366.42	195.87	170.55	7.50	36.16	4.40	21.20

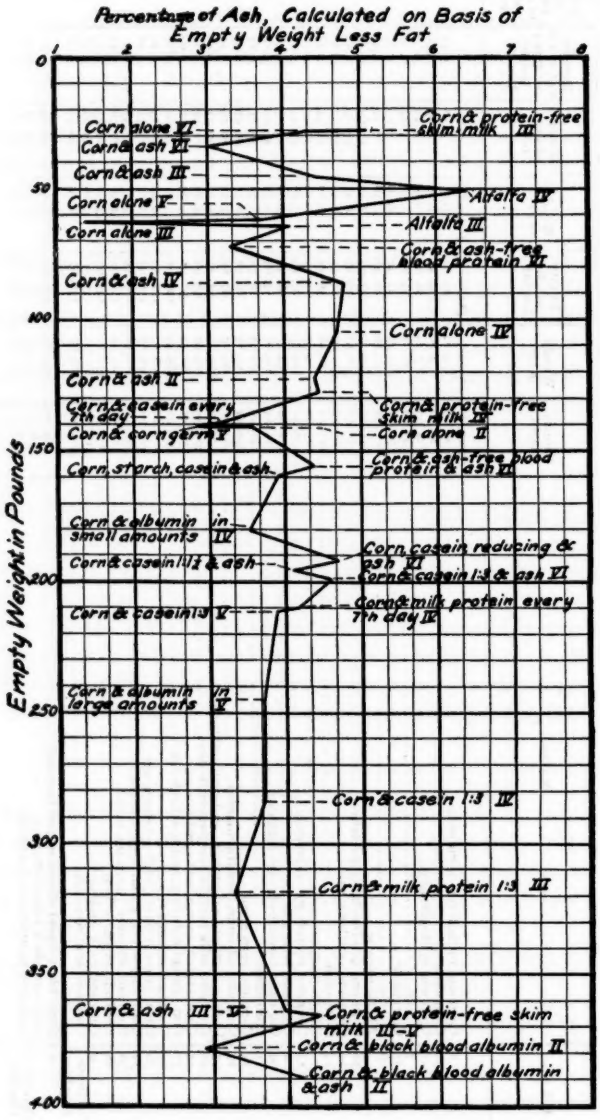

FIG 4.—Graph showing the relation between percentage of ash, calculated on basis of empty weight less fat, and empty weight.

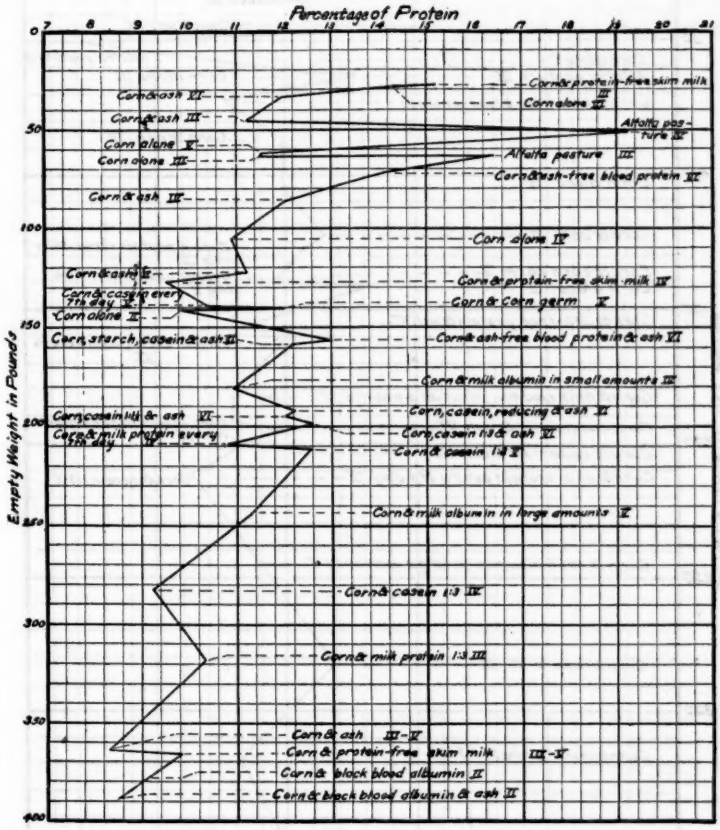
Percentage of Protein
Empty Weight in Pounds
Corn & protein-free skim milk
Corn alone VII
Corn & ash VII
Corn & ash III
Alfalfa pasture IV
Corn alone V
Corn alone III
Alfalfa pasture III
Corn & ash-free blood protein VII
Corn & ash III
Corn alone IV
Corn & ash V
Corn & protein-free skim milk IV
Corn & casein every 7th day V
Corn & Corn germ V
Corn alone V
Corn, starch, casein & ash VI
Corn & ash-free blood protein & ash VI
Corn & milk albumin in small amounts III
Corn, casein 1:1 & ash VI
Corn, casein, reducing & ash VI
Corn & milk protein every 7th day V
Corn, casein 1:3 & ash VI
Corn & casein 1:1 V
Corn & milk albumin in large amounts V
Corn & casein 1:3 IV
Corn & milk protein 1:3 III
Corn & ash III-V
Corn & protein-free skim milk III-V
Corn & black blood albumin V
Corn & black blood albumin & ash V

FIG. 5.—Graph showing the relation between percentage of protein and empty weight.

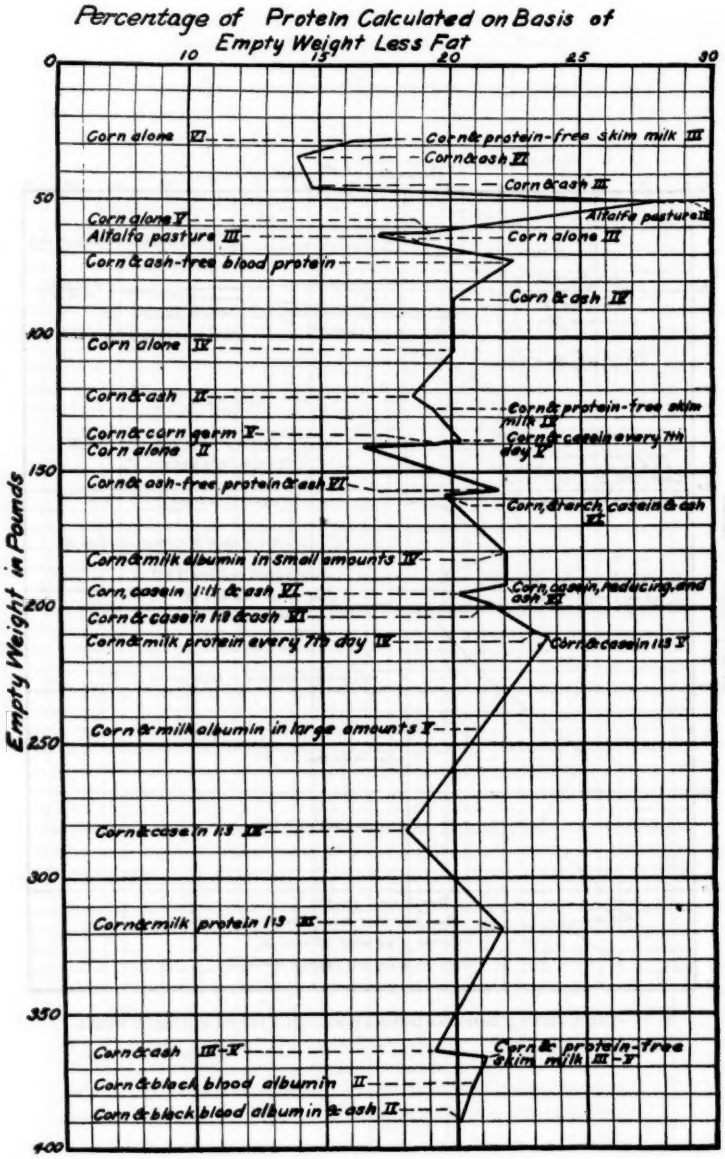
Percentage of Protein Calculated on Basis of Empty Weight Less Fat
0
10
15
20
25
30
50
100
150
200
250
300
350
400
Empty Weight in Pounds
Corn alone VI
Corn & protein-free skim milk III
Corn & ash VI
Corn & ash III
Corn alone V
Alfalfa pasture II
Alfalfa pasture III
Corn alone III
Corn & ash-free blood protein
Corn & ash IV
Corn alone IV
Corn & ash II
Corn & protein-free skim milk IV
Corn & corn germ V
Corn & casein every 7th day V
Corn alone II
Corn & ash-free protein & ash VI
Corn, starch, casein & ash VI
Corn & milk albumin in small amounts IV
Corn, casein 1:1½ & ash VII
Corn, casein, reducing, and ash VI
Corn & casein 1:3 & ash VII
Corn & milk protein every 7th day IV
Corn & casein 1:3 V
Corn & milk albumin in large amounts V
Corn & casein 1:3 VII
Corn & milk protein 1:3 III
Corn & ash III-V
Corn & protein-free skim milk III-V
Corn & black blood albumin II
Corn & black blood albumin & ash II

FIG. 6.—Graph showing the relation between percentage of protein, calculated on basis of empty weight less fat, and empty weight.

4. In a pig fed a ration sufficient to produce a large and rapid growth, producing a body weight above 225 pounds, the fat percentage increases as the weight increases, and the moisture percentage decreases. The prolonged feeding of a deficient ration produces the same result—namely, a pig with a high percentage of fat and a low percentage of moisture, provided the pig attains large size.

5. The percentage of protein appears to decrease as the pigs increase in size. This is due to the large increase in percentage of fat. If the percentage of protein is calculated on the basis of body weight less fat, the percentage does not show any tendency to decrease as pigs increase in size.

6. The percentage of ash appears to decrease with the increasing body weight. This is due to the large proportionate increase in fat. If the ash percentage is calculated on body weight less fat, the larger pigs have as high an ash content in the tissues not fat as the lighter pigs.

7. The general character of the ration affects the composition of the body as follows: A large amount of protein or ash will not produce a pig with a high protein or ash content. Such a ration will produce a rapid growth, and the pig will have the same composition as a pig of the same size fed a ration restricted in protein or ash but whose growth took place over a longer period of time. The best illustrations of this fact are the two continuation hogs, one fed corn and ash and the other corn and protein-free skim milk, in comparison with the hogs in experiment II, in which one was fed corn and black blood albumen and the other the same ration plus ash.

8. A large amount of ash in the ration will not materially influence the percentage of ash in the body. The ash percentage in pigs fed rations sufficient for growth tends to remain fairly constant, if the percentage is calculated on the basis of body weight less fat.

9. There is a closer relation between a pig's size and its composition than between the character of the ration and the pig's composition. If growth has not been too much restricted, the composition of a slaughtered pig of a given weight may be used to calculate the pounds of chemical constituents in another pig not slaughtered. However, this must be done with judgment based upon knowledge regarding the history and condition of the pigs.

II. CHARACTER OF RATION IN ITS EFFECT ON THE DEVELOPMENT OF LUNGS, HEART, LIVER, AND KIDNEYS

That the character of the ration in respect to its nutritive properties has the same relative effect on the development of the internal organs as on the development of the body as a whole is borne out by evidence furnished by a number of investigators. Emmett (*2*) and associates fed three lots of pigs on low, medium, and high protein rations. The amounts

of digestible protein per day per 100 pounds live weight for the three lots were, respectively, 0.32 pound, 0.70 pound, and 0.94 pound.

The weights of the kidneys of the pigs of the low protein lot were about 50 per cent lower than those of the pigs of the medium and high protein lots. The data for the other urinary organs and for the organs of the central nervous system did not show any lot differences that seemed significant. . . . The weights of the heart, liver, spleen, pancreas, gall bladder, and lungs of the pigs from the three lots varied more or less directly with the live weight of the animals.

Carroll and Emmett (*1*) report investigations on 21 lambs, divided into three lots, fed on (1) low, (2) medium, and (3) high protein planes.

Slaughter tests showed that with the exception of the kidneys, the feed has little or no effect on the development of the brain, kidneys, liver, and heart. The kidneys seemed to increase directly with the protein feed. Individuality seems to be a very great factor, in fact, greater than the feed.

Forbes (*3*) notes that with pigs fed corn alone the liver, kidneys, lungs, and heart all compose an abnormally small proportion of the increase and the fat composes an abnormally large proportion of the increase. Sanborn (*8*, *9*, *10*) concludes from his investigations that the corn-fed hogs had a less abundant coat of hair, smaller spleen, liver, and kidneys, and smaller bones. Henry (*6*) found that the corn-fed hogs had an abnormally small amount of hair and a thin skin. The spleen, liver, and kidneys were unusually small, while the brain, heart, and lungs were not affected.

The slaughter tests made on the pigs fed the various rations, the results of which are recorded in Table VI, furnished abundant material for the study of the effect of these rations on the development of the internal organs—heart, lungs, liver, and kidneys. At the time of slaughter, these organs were weighed as soon as removed from the body on a scale accurate to 0.01 pound. The accuracy of the weights depends, of course, on the uniformity in separating these organs from their supporting tissues at relatively the same place. This involves considerable error, as is well known to all who are familiar with this class of work. Just how large this error is can not be determined. If a large number of tests were made on similar pigs, these variations would be eliminated in the average.

The figures as obtained are given in Table VI, and they are arranged in order of increasing weights. A study of these figures will show that, on the whole, these organs increase in weight as the body increases in weight, but not in the same proportion. The smaller pigs have relatively larger organs. This is due to the increase in fat in the larger pigs. The increase in fat takes place faster than the increase in any other constituent or parts of the body. But even allowing for this, the larger pigs do not uniformly have larger organs than smaller pigs. Thus, variations can not be correlated with the different rations fed and must be due to the individuality of the animals. From the results of the analysis of the

pig the pounds of protein were calculated. These weights of protein, arranged in the order of increasing weights, are found in Table VII. This same table gives also the ratio between the weight of protein and the weight of the internal organs.

TABLE VI.—*Relation of the weight of lungs, heart, liver, and kidneys to the empty weight*

Experiment No.	Ration.	Empty weight.	Lungs.	Heart.	Liver.	Kidneys.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
III	Corn and protein-free skim milk.	28.06	1.68	0.25	0.88	0.15
VI	Corn alone.	28.60	1.04	.16	1.04	.12
VI	Corn and ash.	34.37	.82	.18	.84	.10
III	do.	45.62	.68	.16	.74	.13
IV	Alfalfa pasture.	51.25	.82	.22	1.12	.24
V	Corn alone.	62.71	.92	.24	1.54	.24
III	do.	63.28	.53	.17	.56	.11
III	Alfalfa pasture.	63.60	.98	.23	1.61	.30
VI	Corn and ash-free blood protein.	72.18	.94	.24	1.20	.28
IV	Corn and ash.	86.40	1.59	.26	1.58	.17
IV	Corn alone.	105.25	2.06	.36	1.56	.20
II	Corn and ash.	122.80	1.36	.32	2.14	.24
IV	Corn and protein-free skim milk.	127.45	1.38	.36	2.36	.22
V	Corn and casein every seventh day.	139.84	1.08	.46	2.64	.30
V	Corn and corn germ.	140.44	1.04	.42	2.78	.34
II	Corn alone.	141.49	1.56	.50	2.06	.32
VI	Corn, ash-free blood protein, and ash.	156.86	.96	.32	2.60	.46
VI	Corn, starch, casein, and ash.	159.35	1.42	.40	2.56	.38
IV	Corn and albumin (small amounts).	180.99	1.35	.49	2.17	.29
VI	Corn, casein reducing, and ash.	192.20	1.22	.36	3.04	.46
VI	Corn, casein 1 to 1½, and ash.	195.66	1.34	.44	3.36	.50
VI	Corn, casein 1 to 3, and ash.	199.71	1.65	.38	3.04	.69
IV	Corn and milk protein every seventh day.	209.95	1.44	.91	1.90	1.06
V	Corn and casein 1 to 3.	211.22	1.52	.66	2.98	.58
V	Corn and albumin (large amounts).	245.15	1.62	.72	3.02	.44
IV	Corn and casein 1 to 3.	282.58	2.82	.72	3.66	.50
III	Corn and milk protein 1 to 3.	318.93	2.89	.63	4.81	.95
III–V	Corn and synthetic ash.	364.52	1.90	1.00	5.40	.50
III–V	Corn and protein-free skim milk.	366.42	2.08	.96	4.86	.58
II	Corn and black-blood albumen.	378.20	2.62	.88	4.34	.62
II	Corn, black-blood albumen, and ash.	389.26	2.55	.98	4.00	.85

A study of Table VII shows that:

1. In general the weights of these internal organs increase with the increase in weight of protein.

2. The variations are irregular and do not seem to have any specific relation to the character of the ration. The variation from the normal must be due to the individuality of the animal.

3. A ration which contains the nutrients for the normal development of the pig will develop the internal organs in the same ratio.

TABLE VII.—*Relation of the weight of the lungs, heart, liver, and kidneys to the weight of protein*

Experiment No.	Ration.	Protein.	Lungs to protein, 1 to	Heart to protein, 1 to	Liver to protein, 1 to	Kidneys to protein, 1 to
		Pounds.				
VI	Corn alone	4.09	3.93	25.56	3.93	34.08
VI	Corn and ash	4.15	5.06	23.07	4.94	41.50
III	Corn and protein-free skim milk	4.27	2.54	17.08	4.95	28.48
III	Corn and ash	5.14	7.56	32.13	6.94	39.53
V	Corn alone	7.20	7.85	30.02	4.68	30.02
III	do	7.22	13.65	42.45	12.92	65.63
VI	Corn and ash-free blood protein	10.19	10.80	42.49	8.49	10.19
IV	Corn and ash	10.35	6.51	39.85	6.55	60.86
III	Alfalfa pasture	10.44	10.65	45.41	6.48	34.77
IV	Corn alone	11.34	5.50	31.53	7.27	56.70
IV	Alfalfa pasture	11.64	14.20	52.96	10.39	48.53
IV	Corn and protein-free skim milk	12.11	8.77	33.67	5.13	55.10
II	Corn and ash	12.67	9.32	39.66	5.92	52.83
II	Corn alone	12.81	8.21	25.62	6.22	40.10
V	Corn and casein every seventh day.	14.61	13.53	31.70	5.53	48.70
V	Corn and corn germ	16.90	16.25	40.22	6.08	49.69
VI	Corn, starch, casein, and ash	19.45	13.70	48.63	7.60	51.15
IV	Corn and milk albumin (small amounts).	19.50	14.44	39.78	8.99	67.28
VI	Corn, ash-free blood protein, and ash.	20.43	21.25	63.95	7.86	44.33
IV	Corn and milk protein every seventh day.	22.59	14.30	24.85	11.89	21.31
VI	Corn, casein 1 to 1½, and ash	23.54	17.57	53.44	7.01	47.08
VI	Corn, casein reducing, and ash	23.64	19.38	65.72	7.78	51.30
VI	Corn, casein 1 to 3, and ash	25.33	15.35	66.62	8.33	36.73
IV	Corn and casein 1 to 3	26.63	6.97	37.02	7.28	53.26
V	do	26.73	17.59	40.63	8.97	45.98
V	Corn and albumin (large amounts).	27.78	17.15	38.61	9.20	63.06
III–V	Corn and synthetic ash	30.34	15.97	30.34	5.61	60.68
II	Corn, black-blood albumen, and ash.	31.89	12.51	32.53	7.97	37.63
III	Corn and milk protein 1 to 3	33.08	11.45	52.60	6.88	34.82
II	Corn and black-blood albumen	33.59	12.82	38.29	7.74	33.59
III–V	Corn and protein-free skim milk	36.16	17.39	37.61	7.44	62.20

LUNG WEIGHTS IN RELATION TO EMPTY WEIGHT AND WEIGHT OF PROTEIN

The figures for the weight of lungs in relation to empty weight are plotted in figure 7, and those in relation to weight of protein in figure 8. The empty weights and the weights of protein are used as the abscissas and the weights of the organs as ordinates. The weights of protein were approximately one-tenth of the empty weight, and to make the curves more comparable the protein figures were multiplied by 10. As pigs increase in size or in amount of protein, the lungs increase irrespective of the nature of the ration.

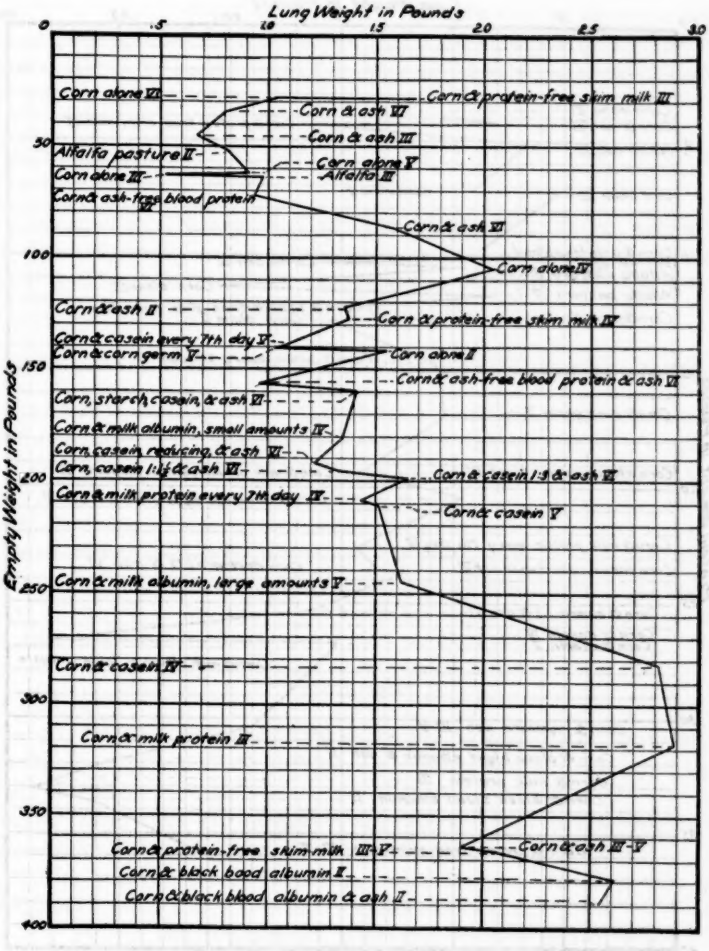

FIG. 7.—Graph showing the relation between weight of lungs and empty weight.

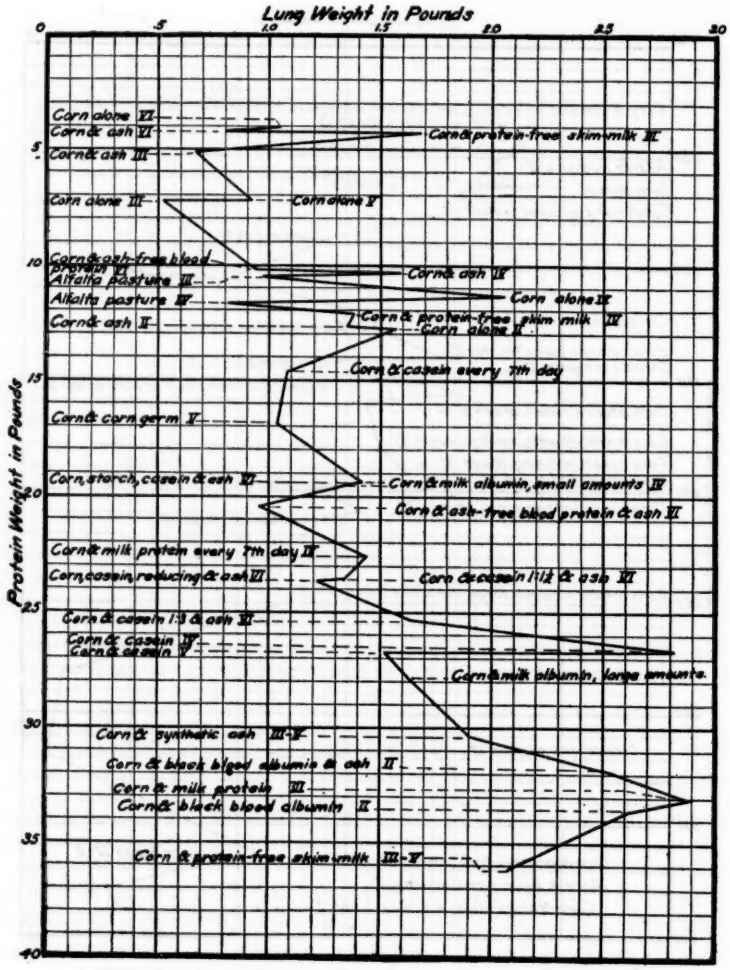

FIG. 8.—Graph showing the relation between weight of lungs and weight of body protein.

HEART WEIGHTS IN RELATION TO EMPTY WEIGHT AND TO WEIGHT OF PROTEIN

The figures for the weight of the heart in relation to empty weight are plotted in figure 9, and in relation to protein weights in figure 10. The figures for empty weight and protein weight are used as abscissas, and the weights of heart, expressed in tenths of a pound, are used as ordinates. The weight of the heart increases as the size of the body or as the amount of protein increases even more regularly than the weight of lungs.

WEIGHT OF THE LIVER IN RELATION TO EMPTY WEIGHT AND WEIGHT OF PROTEIN

The curve for the weights of the liver in relation to empty weight is plotted in figure 11, and in relation to protein weights in figure 12. The weights of the liver seem to vary in proportion to the empty weight or the weight of the protein more than any of the other organs studied.

KIDNEY WEIGHT IN RELATION TO EMPTY WEIGHT AND WEIGHT OF PROTEIN

The relation between the weight of the kidneys and the empty weight, and also between the kidney weight and the weight of protein, is graphically presented in figures 13 and 14. The kidneys become larger as the pigs increase in size, and this increase in size is very irregular. There seems to be no correspondence between the character of ration and the size of kidney. The largest kidneys weighed 1.06 pounds and were found in the pig fed corn and milk protein every seventh day. The kidneys in the pig in the same experiment fed seven times this amount of protein weighed 0.95 pound.

CONCLUSIONS

1. The specific character of the ration has, in general, the same effect on the development of the internal organs as on the development of the body as a whole.

2. A ration that will produce a large development of the body as a whole will also produce large development of the internal organs.

3. The relative smallness of the internal organs in some pigs of restricted growth is due to the overdevelopment of fat.

4. In general, the development of internal organs is also in proportion to the increase of protein. A ration that will produce a large amount of protein will produce large internal organs.

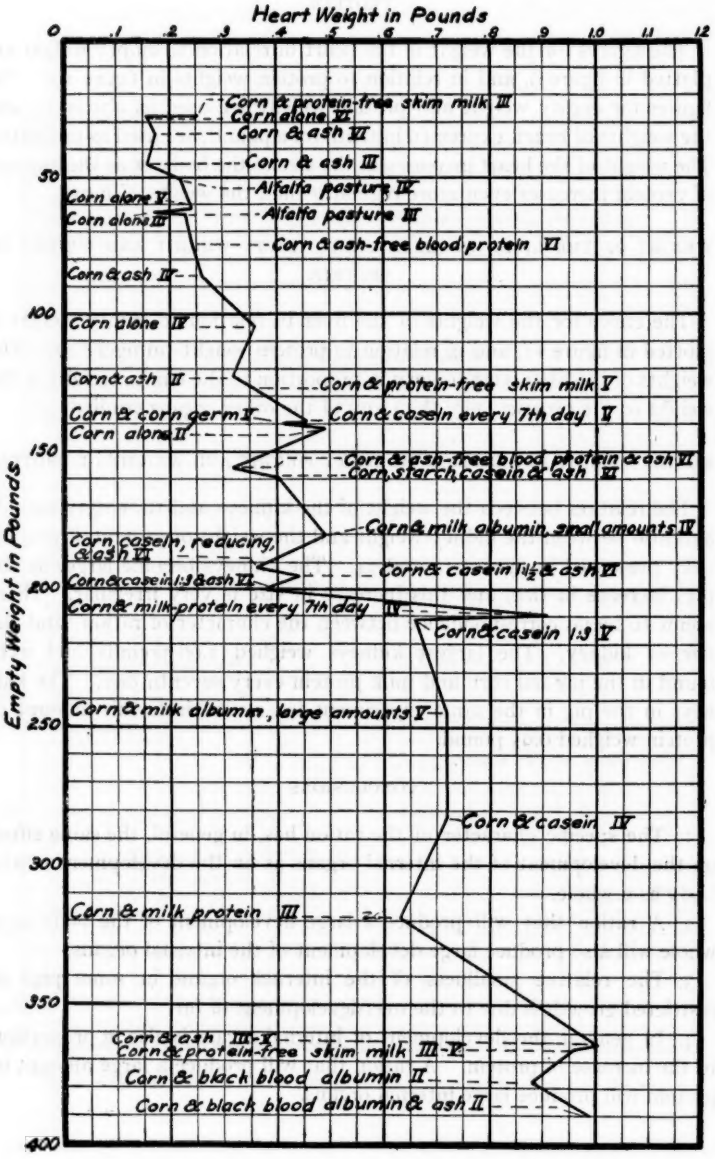

FIG. 9.—Graph showing the relation between weight of heart and empty weight.

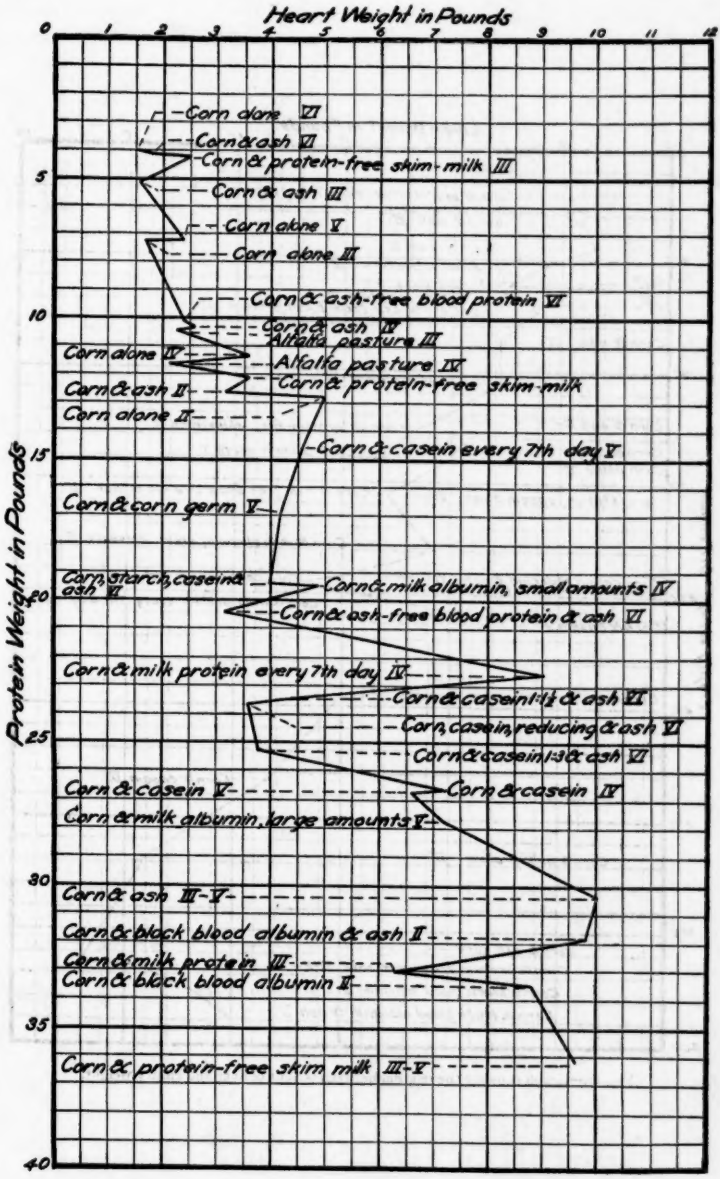
Heart Weight in Pounds
0 1 2 3 4 5 6 7 8 9 10 11 12
Protein Weight in Pounds
5
10
15
20
25
30
35
40
Corn alone VI
Corn & ash VI
Corn & protein-free skim-milk III
Corn & ash III
Corn alone V
Corn alone III
Corn & ash-free blood protein VI
Corn & ash IV
Alfalfa pasture III
Corn alone IV
Alfalfa pasture IV
Corn & ash II
Corn & protein-free skim-milk
Corn alone II
Corn & casein every 7th day V
Corn & corn germ V
Corn, starch, casein & ash VI
Corn & milk albumin, small amounts IV
Corn & ash-free blood protein & ash VI
Corn & milk protein every 7th day IV
Corn & casein 1:½ & ash VI
Corn, casein, reducing & ash VI
Corn & casein 1:3 & ash VI
Corn & casein V
Corn & casein IV
Corn & milk albumin, large amounts V
Corn & ash III-V
Corn & black blood albumin & ash II
Corn & milk protein III
Corn & black blood albumin II
Corn & protein-free skim milk III-V

FIG. 10.—Graph showing the relation between weight of heart and weight of body protein.

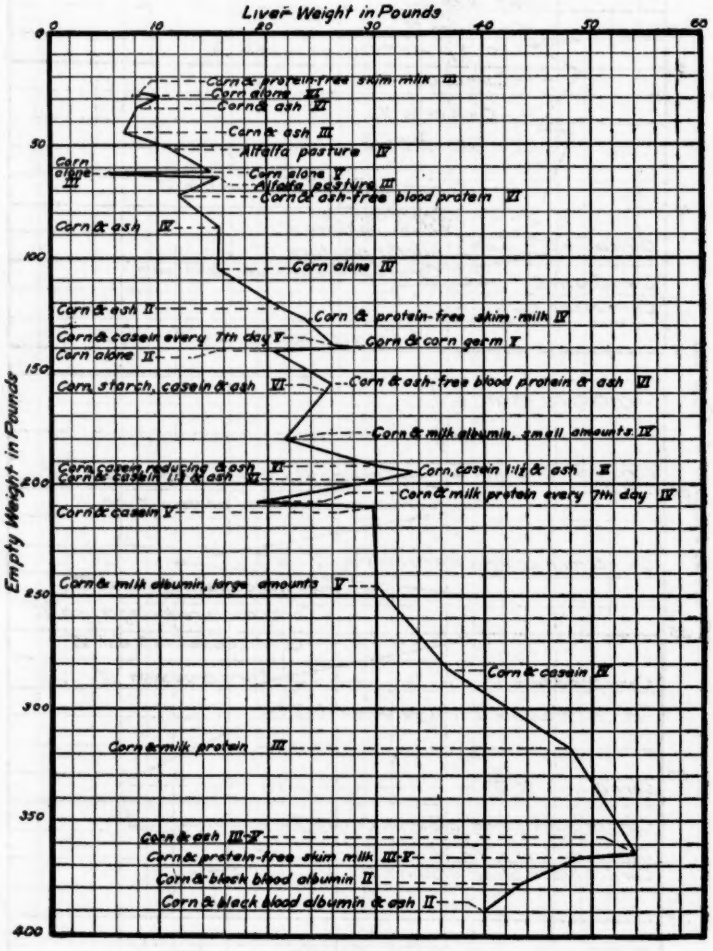

FIG. 11.—Graph showing the relation between weight of liver and empty weight.

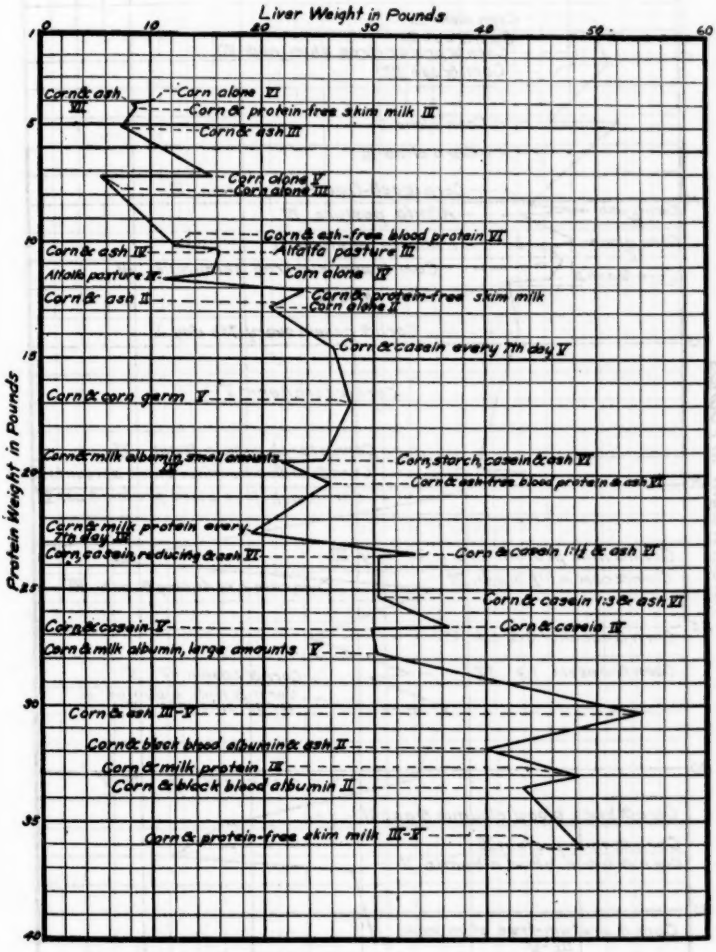

FIG. 12.—Graph showing the relation between weight of liver and weight of body protein.

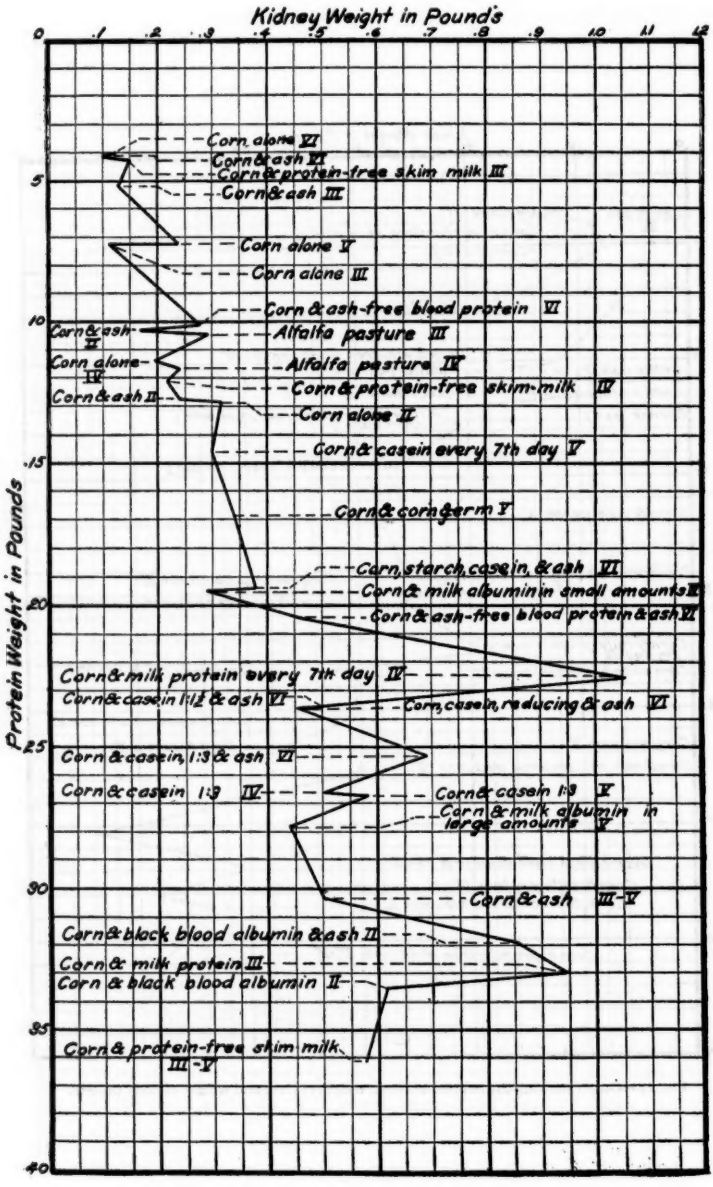
Kidney Weight in Pound's
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2
Protein Weight in Pounds
5
10
15
20
25
30
35
40
Corn alone VI
Corn & ash VI
Corn & protein-free skim milk III
Corn & ash III
Corn alone V
Corn alone III
Corn & ash-free blood protein VI
Corn & ash VI
Alfalfa pasture III
Corn alone VI
Alfalfa pasture IV
Corn & ash II
Corn & protein-free skim-milk III
Corn alone II
Corn & casein every 7th day V
Corn & corn germ V
Corn, starch, casein, & ash VI
Corn & milk albumin in small amounts II
Corn & ash-free blood protein & ash VI
Corn & milk protein every 7th day IV
Corn & casein 1:2 & ash VI
Corn, casein, reducing & ash VI
Corn & casein, 1:3 & ash VI
Corn & casein 1:3 IV
Corn & casein 1:3 V
Corn & milk albumin in large amounts V
Corn & ash III-V
Corn & black blood albumin & ash II
Corn & milk protein III
Corn & black blood albumin II
Corn & protein-free skim milk III-V

FIG. 13.—Graph showing the relation between weight of kidney and empty weight.

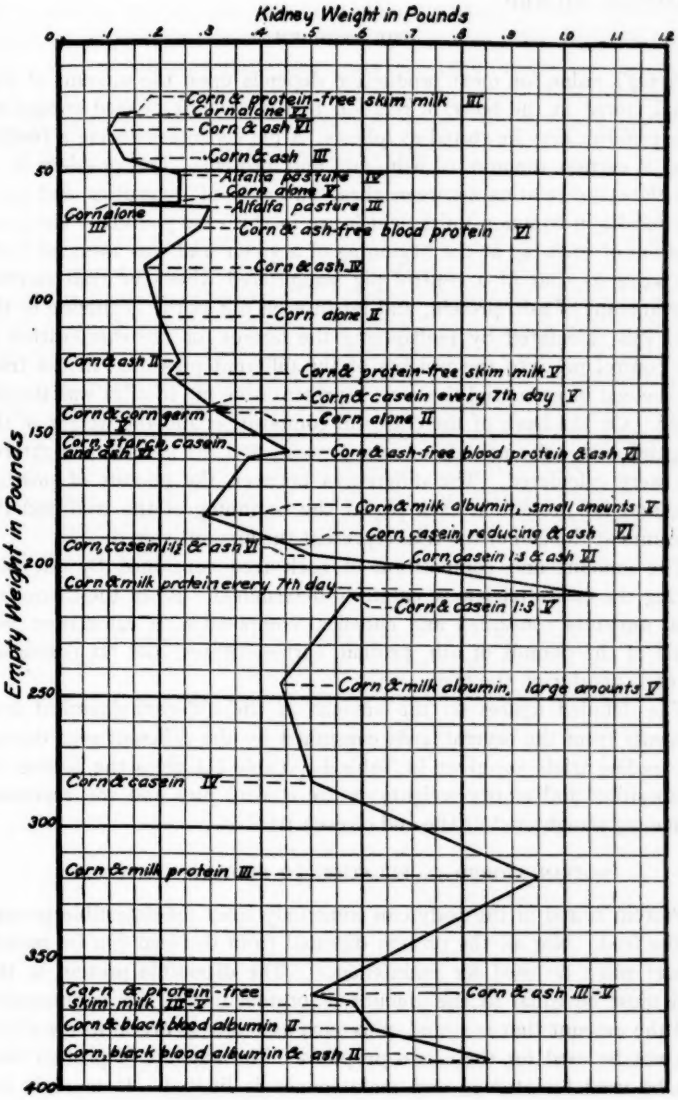
Kidney Weight in Pounds
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2
Empty Weight in Pounds
50
100
150
200
250
300
350
400
Corn & protein-free skim milk III
Corn alone VI
Corn & ash VI
Corn & ash III
Alfalfa pasture IV
Corn alone VI
Alfalfa pasture III
Corn alone III
Corn & ash-free blood protein VI
Corn & ash IV
Corn alone II
Corn & ash II
Corn & protein-free skim milk V
Corn & casein every 7th day V
Corn & corn germ V
Corn alone II
Corn, starch, casein and ash VI
Corn & ash-free blood protein & ash VI
Corn & milk albumin, small amounts V
Corn casein reducing & ash VI
Corn, casein 1:1 & ash VI
Corn, casein 1:3 & ash VI
Corn & milk protein every 7th day
Corn & casein 1:3 V
Corn & milk albumin, large amounts V
Corn & casein IV
Corn & milk protein III
Corn & protein-free skim milk III-V
Corn & ash III-VI
Corn & black blood albumin II
Corn, black blood albumin & ash II

FIG. 14.—Graph showing the relation between weight of kidney and weight of body protein.

III. RELATION BETWEEN THE AMOUNT OF CHEMICAL CONSTITUENTS CONSUMED DURING THE FEEDING TRIALS AND THE AMOUNT STORED

THE PROBLEM

A pig's value for meat production depends upon the amount of material stored in the body in relation to the amount of feed consumed. The problem may be stated as follows: A pig consumes during a feeding trial a certain amount of ash, fat, and protein. The problem is to calculate the relation between these two sets of quantities and state the results in common units, which are in this case pounds. The composition of each pig at the beginning of a given trial was assumed to be the same as that of a control pig slaughtered when the trial started. The amount of ash, protein, and fat in each pig at the beginning of the trial was calculated by multiplying the figures for the composition of the control pig into the weights of the different pigs used in the trial. At the end of each trial the most representative pig in a lot was slaughtered. On the basis of the chemical composition and the weight of the emptied body, the pounds of ash, protein, and fat in each slaughtered pig were calculated. The differences between the pounds of protein, ash, and fat present in each pig at the beginning of the trial and the amounts at the end of the trial represent the amount stored.

The amount and composition of each feed consumed by the pigs during the entire trial were carefully determined. From the figures on total amounts consumed and chemical composition, a calculation was made of the pounds of ash, protein, carbohydrates, and fat consumed by each pig during the trial.

The detailed figures on the amount of the different chemical constituents from the several feeds consumed by the different pigs during the feeding trials are given in Table I. Table III gives the figures for composition and empty weights of the control pigs and the representative pig slaughtered at the end of each trial.

PROTEIN STORED IN RELATION TO PROTEIN CONSUMED

Protein stored in the body can come only from the digestible protein in the feed. Not all the protein digested from the feed can be stored; a part must be used for maintenance. The digestible protein in the feed must be equal to the amount of protein needed for maintenance and the amount that is stored, plus such amounts as are in forms which can not be used for these two purposes. The amount of protein that can be used for storage and maintenance is limited. If more is fed than is needed for these two purposes it may be used for the production of heat and energy, or fat. A protein is made up of a number of amino acids. These acids must be present in the feed in the proportion required by the needs of the body. The amount of protein that can be

stored in the body and the amount that can be used for maintenance are measured by the minimal amount of any amino acid absolutely required. A protein that has a small proportion of any amino acid absolutely needed is less efficient than one in which the different amino acids are so balanced that they meet the requirements of the body. A protein that has a small amount of any amino acid absolutely needed is efficiently supplemented by another protein which has a relatively large proportion of this particular amino acid.

FIVE PIGS THAT WERE STARVED

The experiments reported herewith extended over a period of five years. The same feed gave different results in different years. The individuality of pigs played a part. There were five pigs in these different trials which either lost weight or made such small gains that they were evidently starving. Two pigs, one fed corn and ash and the other fed corn and protein-free skim milk in experiment III, lost protein from the body. Three pigs, one fed corn and ash and one fed corn alone (experiment VI), and also one pig fed corn alone (experiment III), stored very small amounts of protein in proportion to the amount fed. These last three stored only 1 pound of protein for 24 pounds consumed. This is an abnormally wide ratio. These five pigs will be eliminated in the further discussion.

PROTEIN STORED FROM CORN FED ALONE OR WITH ASH

Zein is the protein in corn which occurs in larger amounts than any other. This protein is deficient in that it lacks the two amino acids, lysin and tryptophane, both necessary for growth and development.

TABLE VIII.—*Relation of protein stored to protein consumed*

Experiment No.	Ration.	Protein stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
		Pounds.	*Pounds.*	*Pounds.*	
V	Corn alone	3.76	27.25	.....	1:7.25
IV	Corn and ash	4.58	31.72	.....	1:6.92
IV	Corn alone	4.86	41.87	.....	1:8.62
IV	Corn and protein-free skim milk	5.36	37.17	3.24	1:7.54
II	Corn and ash	5.70	36.07	.....	1:6.32
II	Corn alone	6.30	42.58	.....	1:6.77
III–V	Corn and ash (continuation hog)	24.63	203.73	.....	1:8.30
III–V	Corn and protein-free skim milk (continuation hog)	29.75	190.75	16.03	1:6.95

There were three pigs fed on corn alone, three fed corn supplemented with ash, and two fed corn supplemented with protein-free skim milk. This substance contained a small amount of nitrogenouscompo unds

and most of the ash from the milk. The quantity obtained from 3 pounds of milk was fed for each pound of corn. These two pigs were continued on these rations until they were nearly 3 years old. Figures on the feed and growth of the eight pigs, showing the ratio of the protein stored to the protein consumed, are given in Table VIII.

The average ratio of the protein stored to the protein consumed for all these pigs is 1 to 7.5. As corn was practically the sole source of protein for all these pigs it means that when they are fed corn alone pigs will store 1 pound of protein for about 7.5 pounds consumed. This is a wide ratio. It is not so much that the protein in corn occurs in too small a proportion but that a large part of this protein is deficient in lysin and tryptophane. These occur in too small proportions in relation to the amount of other substances which can be used only for the production of fat.

The fact that the two pigs fed until nearly 3 years old on a deficient ration stored protein in the same ratio as the younger pigs should be noted. The fact that these pigs did not grow for over a year at the beginning of the trial means that there was a period in the life of these two pigs when the storage of protein in relation to the amount consumed was much less than the average ratio for the whole life period; and accordingly there must have been a time when the storage of protein took place in a much narrower ratio. The development of these two pigs will be studied in a subsequent section of this paper.

PROTEIN STORED FROM CORN SUPPLEMENTED WITH A SMALL AMOUNT OF PROTEIN FROM MILK

The two proteins in milk, casein and albumin, contain the two amino acids, lysin and tryptophane, both missing in zein. As milk is the natural food for young mammals, it is expected that the proteins in milk should contain the materials needed for growth. How much protein is needed from milk in order to supplement the protein in corn? Table IX gives the figures on the feed and growth of three pigs fed small amounts of supplementary milk protein and shows the ratios of protein stored to protein consumed.

TABLE IX.—*Relation of protein stored to protein consumed*

Experiment No.	Ration.	Protein stored.	Protein consumed.		Ratio.
			From corn.	From milk.	
		Pounds.	*Pounds.*	*Pounds.*	
IV.....	Corn and milk albumin.....	14. 14	59. 00	6. 71	1:4. 65
IV.....	Corn and milk protein every seventh day.....	15. 71	66. 60	8. 00	1:4. 75
V.....	Corn and casein every seventh day...	10. 26	55. 16	5. 61	1:5. 93

The milk albumin obtained from 3 pounds of milk was fed for each pound of corn. The seventh day means that corn was fed alone for six days and on the seventh day the total protein from 3 pounds of milk or the casein equivalent was fed for each pound of corn. These small amounts of supplementary protein, from one-eighth to one-tenth of the total protein furnished, resulted in a ratio of protein storage of 1 to 5.11, as compared with 1 to 7.5 when corn was fed alone.

PROTEIN STORED WHEN CORN WAS SUPPLEMENTED WITH A MEDIUM AMOUNT OF PROTEIN FROM MILK

There were two pigs fed proteins from milk in medium amounts. One was fed the casein from 1.5 pounds of milk for each pound of corn. This ration is designated corn and casein 1 to 1.5. The other pig was fed casein in such amounts that the nutritive ratio which at first was 1 to 3 was gradually widened until it was 1 to 8. The amount of protein from milk supplied to the pig fed corn and casein 1 to 1.5, was nearly two-sevenths of the total, and the other pig received nearly one-third of his protein from milk. These two pigs stored protein in a ratio half as wide as those pigs fed corn alone. This proportion of protein from milk was more efficient than greater or smaller amounts. Figures on the feed and growth of these two pigs showing the ratio of the protein stored to the protein consumed are shown in Table X.

TABLE X.—*Relation of protein stored to protein consumed*

Experiment No.	Ration.	Protein stored.	Protein consumed.		Ratio.
			From corn.	From milk.	
		Pounds.	*Pounds.*	*Pounds.*	
VI.....	Corn and casein, 1: 1.5.....	21.47	51.03	20.81	1:3.34
VI.....	Corn and casein decreasing.....	21.45	53.07	25.84	1:3.70

PROTEIN STORED WHEN CORN WAS SUPPLEMENTED WITH A LARGE AMOUNT OF PROTEIN FROM MILK

There were five pigs fed protein from milk in large amounts. The term milk protein here means both the casein and the albumin in the proportion in which they occur in milk. The milk protein or the casein from 3 pounds of milk was fed for each pound of corn. The milk albumin was fed in such amounts as to give practically the same amount of protein as the casein from 3 pounds of milk for each pound of corn. In experiment VI, the casein was fed so as to make a nutritive ratio of 1 to 3.3 The figures giving the ratio of protein stored to protein consumed for these five pigs are given in Table XI.

TABLE XI.—*Relation of protein stored to protein consumed*

Experiment No.	Ration.	Protein stored.	Protein consumed.		Ratio.
			From corn.	From milk.	
		Pounds.	*Pounds.*	*Pounds.*	
III.....	Corn and milk protein.....	27.33	90.54	89.39	1:6.58
IV.....	Corn and casein.....	20.18	84.65	66.65	1:7.49
V.....	.....do.....	21.84	65.72	50.72	1:5.33
V.....	Corn and milk albumin.....	24.30	77.04	46.32	1:5.08
VI.....	Corn and casein.....	22.90	47.35	80.70	1:5.59

The protein from milk varied from a little less than one-half to almost two-thirds of the total protein consumed. The amount of protein stored was from about one-half to about one-fourth of the protein supplied by the milk. This is in sharp contrast to the results where minimum or medium amounts of milk protein were fed. When milk protein was fed in minimum amounts the pounds of protein stored were about twice the pounds of protein supplied in the milk. When milk protein was fed in medium amounts the pounds of protein stored were nearly the same as the pounds of milk protein supplied. When milk protein was fed in large amounts, the amount of protein stored was from less than one-third to about one-half what was supplied in the milk. That is, from 3 pounds of milk protein supplied, in addition to what the corn furnished, less than 1 pound was stored. The average ratio of protein storage when large amounts were fed was 1 to 6, as compared with 1 to 3.5 when medium amounts of milk protein were fed or 1 to 7.5 when corn was fed alone.

PROTEIN STORED WHEN CORN WAS SUPPLEMENTED WITH PROTEIN IN LARGE AMOUNTS FROM VARIOUS SOURCES

The proteins from other sources than milk were black blood albumen, corn germ, and ash-free blood protein (p. 280–281). These rations were made up as follows: Black blood albumen constituted a little over 11 per cent of the ration having a nutritive ratio of 1 to 5.10; corn germ was about one-third of the ration having a nutritive ratio of 1 to 8; ash-free blood protein was fed in such amounts as to make a nutritive ration of 1 to 3; starch and casein were added in such amounts as to make a nutritive ratio the same as for corn, or 1 to 8.76. Figures on the feed and growth of six pigs fed on corn supplemented with protein from these sources as indicated, showing the ratio of protein stored to protein consumed, are as given in Table XII.

The wide nutritive ratios with corn and corn germ, or corn, starch, casein, and ash, resulted in the most economical storage of protein. This is in harmony with results presented in the preceding paragraphs.

TABLE XII.—*Relation of protein stored to protein consumed*

Experiment No.	Ration.	Protein stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
		Pounds.	*Pounds.*	*Pounds.*	
II	Corn and black blood albumen	26.28	105.97	129.21	1 : 8.95
II	Corn and black blood albumen and ash	24.27	118.20	142.25	1 : 10.73
V	Corn and corn germ	13.36	31.07	21.47	1 : 3.93
VI	Corn and ash-free blood protein	7.15	22.27	23.61	1 : 6.40
VI	Corn, ash-free blood protein, and ash	18.24	39.29	41.66	1 : 4.43
VI	Corn, starch, casein, and ash	16.85	24.84	22.61	1 : 2.85

When corn was fed alone, the protein was stored in a ratio of 1 to 7.5; with corn germ this ratio was nearly halved, showing the superiority of the protein in the germ over the proteins in the kernel as a whole. The ration corn, starch, casein, and ash resulted in a larger proportion of protein storage in relation to the amount fed than any other ration in this entire series of experiments. It was a wide ratio, but nearly half of the protein came from milk.

The pigs fed the black blood albumen and the ash-free blood protein were fed protein in too large amounts, hence the wide ratio.

GRAPHIC PRESENTATION OF THE RELATION BETWEEN THE AMOUNT OF PROTEIN CONSUMED AND THE AMOUNT OF PROTEIN STORED

The quantitative relations between the amount of protein stored and the amounts of protein consumed are given in figure 15. The bars are arranged according to the increase in protein storage. These bars, representing the amount of protein stored, present a gradually rising curve. This is in contrast to the very irregular heights of the bars representing the amounts of protein consumed. This simply means that the power of the pig to store protein is limited. If protein is fed in small amounts and the protein is of the right kind, as milk protein fed in small amounts, then the ratio between the amount of protein consumed and the amount of protein stored will be narrow. When protein is fed in large amounts, the amount stored will not be increased in proportion no matter what the character of the protein, but it will be stored in a wide ratio.[1] The excess of protein fed will be used for the production of fat or energy. When supplementary proteins were fed in too small amounts, the ratio of protein storage was wider than when these amounts were approximately one-third of the total protein.

[1] The idea here presented should not be confused with rate of growth.

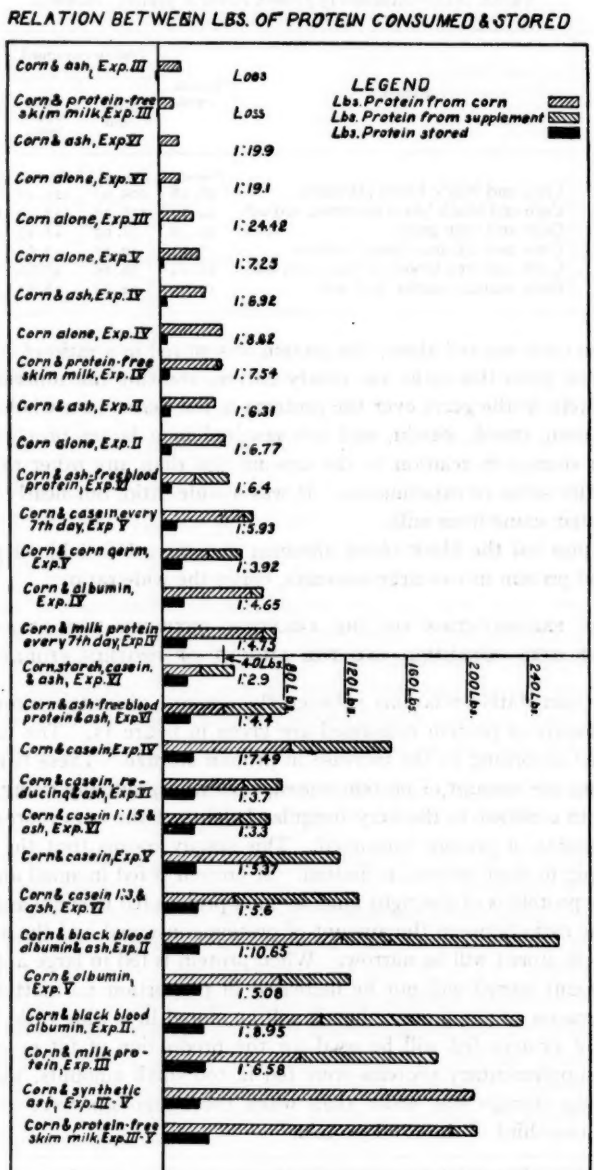

FIG. 15.—Graphical representation of the relation between pounds of protein consumed and pounds of protein stored.

RELATION BETWEEN PROTEIN CONSUMED AND THE SUM OF ASH, PROTEIN, AND FAT STORED

The pig is not an economical machine for the storage of protein. In the preceding pages it has been shown that the most narrow ratio in protein storage was 1 to 2.85. That is, 1 pound of protein was stored for nearly 3 pounds consumed. This pig stored 16.85 pounds of protein, though the ration contained 21.85 pounds of protein from casein and 24.84 pounds from corn. Protein from milk when fed in medium amounts was the most efficient. When other protein from animal sources was used, the ratio was wider. The pig which was fed 142 pounds of protein from black blood albumen and 118 pounds from corn stored only 24.27 pounds of protein, or less than 1 pound for more than 10 pounds consumed. The other principal constituent which the pig stores is fat. While protein can come only from the protein of the feed, the fat can come from the carbohydrates and the fat in the feed and also from the protein. The ash or mineral matter can come only from the ash of the feed.

The problem in this case is to compare the sum of ash, protein, and fat stored by each pig during the experiment with the amount of protein consumed. To what extent does the supplementary protein added to the corn stimulate the storage of these three constituents?

The five pigs noted above, two of which lost weight and the other of which gained only small amounts, will not be included in the comparisons which follow.

SUM OF CONSTITUENTS STORED FROM CORN FED ALONE OR WITH ASH

When pigs were fed corn alone they stored on the average 1 pound of protein for 7.5 pounds consumed. The digestible portion of the other 6.5 pounds of protein, together with the digestible fat and carbohydrates in the ration, were used for the production of energy and for the storage of fat. The amount of total constituents stored are presented in Table XIII, together with the figures on protein consumption.

TABLE XIII.—*Relation of ash plus protein plus fat stored to protein consumed*

Experiment No.	Ration.	Ash plus protein plus fat stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
II	Corn alone	58.46	42.58	.....	1.3:1
II	Corn and ash	46.83	36.07	.....	1.3:1
IV	Corn alone	44.09	41.87	.....	1.1:1
IV	Corn and ash	31.01	31.72	.....	1.0:1
IV	Corn and protein-free skim milk	60.70	37.17	3.24	1.5:1
V	Corn alone	26.55	27.25	.....	1.1:1
III–V	Corn and ash (continuation hog)	231.08	203.73	.....	1.1:1
III–V	Corn and protein-free skim milk	225.67	190.75	16.03	1.1:1

The average from these ratios is a little less than 1.1 to 1. That is, for 1 pound of protein consumed the total of ash, fat, and body protein stored is about 1.1 pounds. The older continuation pigs were using the food as efficiently as the younger pigs. As these two pigs did not start to make satisfactory gains till they were nearly 2 years old, it means that during the third or last year of their life the ratio was narrower than for the younger pigs.

SUM OF CONSTITUENTS STORED FROM CORN SUPPLEMENTED WITH A SMALL AMOUNT OF PROTEIN FROM MILK

The addition to corn of a small amount of protein from milk increased the amount of total constituents stored in ralation to the total protein consumed. This is shown in the figures given in Table XIV.

TABLE XIV.—*Relation of ash plus protein plus fat stored to protein consumed*

Experiment No.	Ration.	Ash plus protein plus fat stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
IV.....	Corn and milk protein every seventh day.....	119.68	66.60	8.00	1.61:1
IV.....	Corn and milk albumin.....	100.21	59.00	6.71	1.52:1
V.....	Corn and casein every seventh day...	75.70	55.16	5.61	1.25:1

The average of these ratios is very nearly 1.46 to 1, or 1.46 pounds of constituents stored for each pound of protein consumed, and shows the distinct advantage of adding this small amount of protein from milk.

SUM OF CONSTITUENTS STORED FROM CORN SUPPLEMENTED WITH A MEDIUM AMOUNT OF PROTEIN FROM MILK

When corn was supplemented with a medium amount of protein from milk amounting to a little less than one-third of the total protein fed, the ratio of constituents stored to protein consumed was 1.41 to 1. There were only two pigs fed with this medium amount of protein. (Table XV.)

TABLE XV.—*Relation of ash plus protein plus fat stored to protein consumed*

Experiment No.	Ration.	Ash plus protein plus fat stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
VI.....	Corn and casein reducing.....	109.08	51.03	20.81	1.52:1
VI.....	Corn and casein 1.5:1.....	103.21	53.07	25.84	1.31:1

Increasing the proportion of protein from milk from about one-tenth of the total to a little less than one-third of the total did not increase the sum of constituents stored for each pound of protein consumed.

SUM OF CONSTITUENTS STORED WHEN CORN WAS SUPPLEMENTED WITH LARGE AMOUNTS OF PROTEIN FROM MILK

The amount of protein storage was increased by adding a small amount of protein from milk, one-tenth of the total, to corn. This was further increased by adding more protein, a little less than one-third of the total. But the effectiveness could not be further increased by adding more protein. When the total constituents were considered, the effectiveness was still more limited. When the supplementary protein was about one-tenth of the total, it was more effective than when corn alone was used, but the effectiveness did not increase further. That the addition of large amounts of protein from milk does not increase the effectiveness over medium amounts is shown in Table XVI.

TABLE XVI.—*Relation of ash plus protein plus fat stored to protein consumed*

Experiment No.	Ration.	Ash plus protein plus fat stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
III	Milk protein (casein and albumin)	184.38	90.54	89.39	1.02:1
IV	Casein 1:3	149.97	84.65	66.65	1.00:1
V	do	119.25	65.72	50.72	1.03:1
V	Milk albumin	138.75	77.04	46.32	1.13:1
VI	Casein 1:3	106.68	47.35	80.70	.83:1

The average of these ratios is 1 to 1, or less than that obtained when corn was fed alone. When milk protein was about one-tenth of the total, the average was 1.46 to 1. When milk protein was about one-third of the total, the average was 1.41 to 1. Increasing the amount of supplementary protein beyond a certain amount will not enable the pig to store more constituents in proportion to the increase in protein added.

AMOUNT OF CONSTITUENTS STORED FROM CORN SUPPLEMENTED WITH LARGE AMOUNTS OF PROTEIN FROM VARIOUS SOURCES

That the total amount of constituents stored in proportion to the amount of protein consumed may be further decreased is shown by the figures given in Table XVII.

The protein from black blood albumen constituted over one-half of the total protein supplied, yet the total constituents stored when this large amount of protein was fed were less in proportion than with any other rations except the ash-free blood protein. The addition of ash to the black blood albumen did not increase its efficiency, but when ash

was added to the ash-free blood protein, the efficiency was greatly increased. The protein from corn germ was as efficient in its effect on the storage of total nutrients as the seventh day feeding of casein. The corn, starch, and casein ration was the most efficient of all the rations tried. About 1⅔ pounds of constituents were stored for each pound of protein consumed. It was shown above that this ration was also the most efficient in relation to protein storage.

TABLE XVII.—*Relation of ash plus protein plus fat stored to protein consumed*

Experiment No.	Ration.	Ash plus protein plus fat stored.	Protein consumed.		Ratio.
			From corn.	From supplement.	
II	Corn and black blood albumen	229.59	105.97	129.21	0.98:1
II	Corn, black blood albumen, and ash	244.21	118.20	142.25	.94:1
V	Corn and corn germ	65.71	31.07	21.47	1.25:1
VI	Corn and ash-free blood protein	31.50	22.27	23.61	.69:1
VI	Corn, ash-free blood protein, and ash	82.85	39.29	41.66	1.03:1
VI	Corn, starch, casein, and ash	78.25	24.84	22.61	1.66:1

GRAPHIC PRESENTATION OF THE RELATION BETWEEN THE PROTEIN CONSUMED AND THE TOTAL GAIN OF CHEMICAL CONSTITUENTS

The relation between the protein consumed and the storage of ash, protein, and fat is shown graphically in figure 16. The bars are arranged in order of the increasing amounts of constituents stored.

The efficiency of corn alone as a ration for growing pigs, as measured by the total constituents stored, can be greatly increased by the addition of a small amount of protein from milk. If the amount of protein from milk is increased above a certain amount, the efficiency of the ration as a whole is decreased. The increase in protein simply increased the rate of growth. This is true when the ratio is narrow. The proteins from blood were the least efficient although they furnished one-half of the total protein. Proteins from milk were the most efficient when fed in a ratio made wide by the addition of starch. The proteins from corn germ, as measured by the total constituents stored, compare well with the proteins from other sources.

INFLUENCE OF QUANTITY OF PROTEIN CONSUMED UPON QUANTITY OF FAT STORED

In the preceding discussion it has been shown that the quantity and quality of protein consumed has a limited influence on the relative quantity of the total ash, protein, and fat stored. On the whole, the more protein that is consumed in the ration the more constituents will be stored; but a ration that is liberal in protein will not store a pro-

portionately larger quantity of these constituents as compared with one that is relatively poor. When corn was the exclusive source of food, the quantity of constituents stored was only 1.1 pounds for each pound of protein consumed. This was increased to 1.46 and 1.66 pounds when milk protein was used in a ration whose nutritive ratio was wide. But

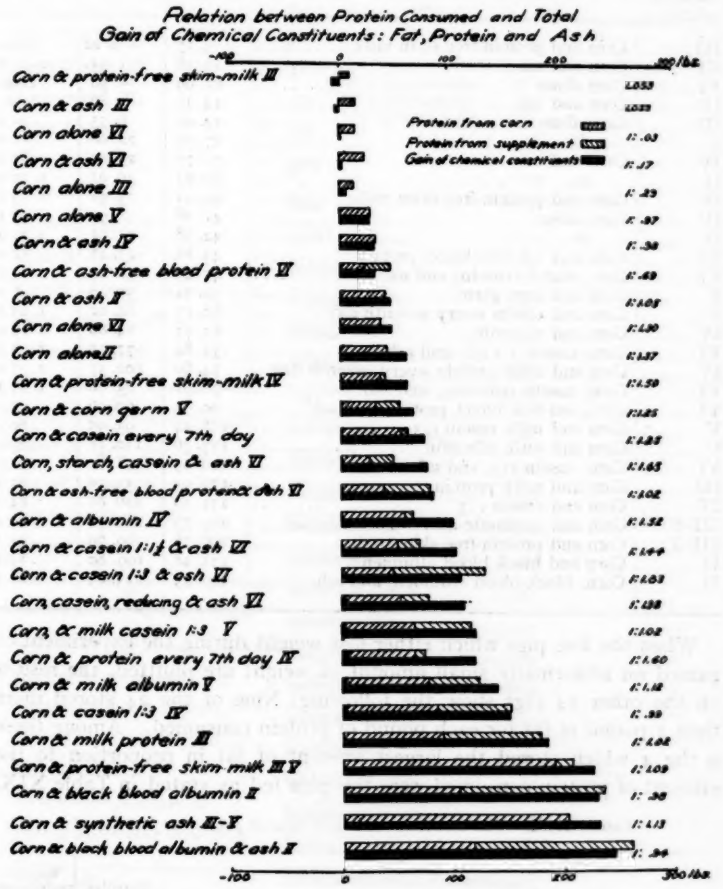
Relation between Protein Consumed and Total Gain of Chemical Constituents: Fat, Protein and Ash
-100
0
100
200
300 lbs.
Protein from corn
Protein from supplement
Gain of chemical constituents
Corn & protein-free skim-milk III
Corn & ash III
Corn alone VI
Corn & ash VI
Corn alone III
Corn alone V
Corn & ash IV
Corn & ash-free blood protein VI
Corn & ash II
Corn alone VI
Corn alone II
Corn & protein-free skim-milk IV
Corn & corn germ V
Corn & casein every 7th day
Corn, starch, casein & ash VI
Corn & ash-free blood protein & ash VI
Corn & albumin IV
Corn & casein 1:1½ & ash VI
Corn & casein 1:3 & ash VI
Corn, casein, reducing & ash VI
Corn, & milk casein 1:3 V
Corn & protein every 7th day IV
Corn & milk albumin V
Corn & casein 1:3 IV
Corn & milk protein III
Corn & protein-free skim milk III V
Corn & black blood albumin II
Corn & synthetic ash III-V
Corn & black blood albumin & ash II
-100
0
100
200
300 lbs.

FIG. 16.—Graphical representation showing the relation between pounds of protein consumed and total pounds of protein, ash, and fat stored.

when large amounts of protein were used the total constituents stored were about 1 pound for each pound of protein consumed.

The pig stores fat in larger quantities than any other constituent, except when of small size. In small pigs moisture is the largest constituent. In pigs of 200 pounds weight or over, fat is by far the largest constituent.

In Table XVIII are given the pounds of protein consumed, the pounds of fat stored, and the ratio of protein consumed to fat stored.

TABLE XVIII.—*Influence of protein consumption on fat storage*

Experiment No.	Ration.	Protein consumed.	Fat stored.	Ratio.
III	Corn and protein-free skim milk	9.27	−6.22	Loss.
VI	Corn and ash	12.36	1.35	0.10:1
VI	Corn alone	12.99	−.58	Loss.
III	Corn and ash	14.41	−2.86	Loss.
III	Corn alone	22.47	6.55	.29:1
V	do	27.25	22.08	.81:1
IV	Corn and ash	31.72	26.05	.82:1
II	do	36.07	39.83	1.10:1
IV	Corn and protein-free skim milk	40.41	53.91	1.33:1
IV	Corn alone	41.88	38.90	.93:1
II	do	42.58	51.02	1.20:1
VI	Corn and ash-free blood protein	45.88	23.48	.51:1
VI	Corn, starch, casein, and ash	47.45	58.29	1.23:1
V	Corn and corn germ	52.54	50.48	.96:1
V	Corn and casein every seventh day	60.77	64.02	1.05:1
IV	Corn and albumin	65.75	84.86	1.29:1
VI	Corn, casein 1:1 1/2, and ash	71.84	77.35	1.08:1
IV	Corn and milk protein every seventh day	74.60	102.37	1.37:1
VI	Corn, casein reducing, and ash	78.91	83.08	1.05:1
VI	Corn, ash-free blood protein, and ash	80.95	60.96	.75:1
V	Corn and milk casein 1:3	116.44	93.95	.80:1
V	Corn and milk albumin	123.36	110.18	.89:1
VI	Corn, casein 1:3, and ash	128.05	78.82	.61:1
III	Corn and milk protein	179.93	153.30	.85:1
IV	Corn and casein 1:3	151.30	126.61	.84:1
III–V	Corn and synthetic ash	203.73	201.34	.99:1
III–V	Corn and protein-free skim milk	206.78	189.69	.92:1
II	Corn and black blood albumen	235.48	199.80	.85:1
II	Corn, black blood albumen, and ash	260.45	215.03	.82:1

When the five pigs which either lost weight during the experiment or gained an abnormally small amount of weight are omitted, the results on the other 24 pigs show the following: Nine of the 24 stored more than 1 pound of fat for each pound of protein consumed. Among these 9 the 4 which stored the largest amount of fat in proportion to the amount of protein consumed were the pigs fed as stated in Table XIX.

TABLE XIX.—*The nutritive ratio and ratio of protein to fats stored*

Ration.	Nutritive ratio.	Ratio of protein consumed to fat stored.
Corn, starch, casein and ash	1 : 8.76	1 : 1.23
Corn and milk protein every seventh day	1 : 7.64	1 : 1.37
Corn and milk albumin	1 : 7.71	1 : 1.29
Corn and protein-free skim milk	1 : 9.44	1 : 1.33

These were all wide nutritive ratios. The pigs which stored the smallest amount of fat in proportion to the amount of protein fed were

the pigs fed the corn and ash-free blood protein and corn and casein in experiment VI. These had a nutritive ratio of 1 to 4 and 1 to 3.34, respectively.

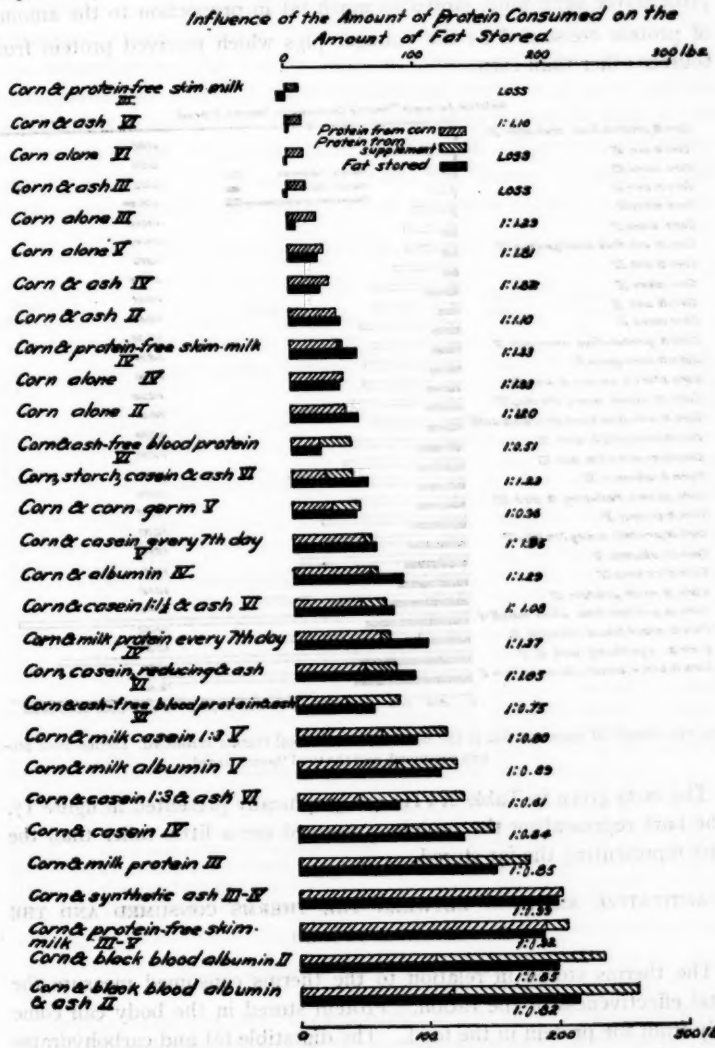

FIG. 17.—Graphical representation of the relation between the amount of protein consumed and the amount of fat stored.

Most of the other pigs stored from 0.8 pound to 1 pound of fat for each pound of protein consumed. The source of protein did not seem to have any distinct influence. The pigs fed on corn and black blood

albumin stored, on the whole, as much fat in proportion to the protein consumed as the pigs fed protein from milk. The two old continuation pigs, one being fed on corn and ash and the other on corn and protein-free skim milk, stored as much fat in proportion to the amount of protein consumed as the younger pigs which received protein from sources other than corn.

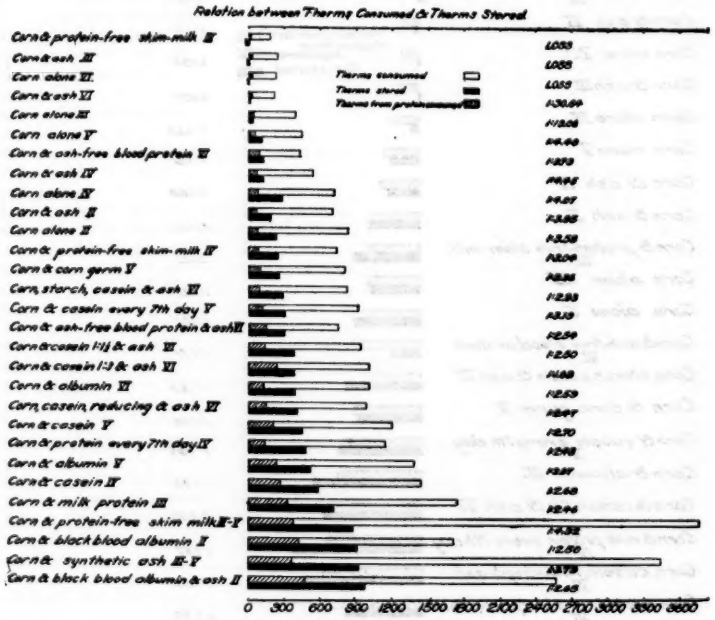
Relation between Therms Consumed & Therms Stored
Therms consumed
Therms stored
Therms from protein
Corn & protein-free skim-milk II
Corn & ash III
Corn alone VI
Corn & ash VI
Corn alone III
Corn alone V
Corn & ash-free blood protein VI
Corn & ash IV
Corn alone IV
Corn & ash II
Corn alone II
Corn & protein-free skim-milk IV
Corn & corn germ V
Corn, starch, casein & ash VI
Corn & casein every 7th day V
Corn & ash-free blood protein & ash III
Corn & casein 1:1 & ash VI
Corn & casein 1:3 & ash VI
Corn & albumin VI
Corn, casein, reducing & ash VI
Corn & casein V
Corn & protein every 7th day IV
Corn & albumin V
Corn & casein IV
Corn & milk protein III
Corn & protein-free skim milk II-V
Corn & black blood albumin I
Corn & synthetic ash III-V
Corn & black blood albumin & ash II
0 300 600 900 1200 1500 1800 2100 2400 2700 3000 3300 3600

FIG. 18.—Graphical representation of the relation between total therms consumed, therms from protein consumed, and the total therms stored.

The facts given in Table XVIII are graphically presented in figure 17. The bars representing the protein consumed are a little taller than the bars representing the fat stored.

QUANTITATIVE RELATION BETWEEN THE THERMS CONSUMED AND THE THERMS STORED

The therms stored in relation to the therms consumed measure the total effectiveness of the ration. Protein stored in the body can come only from the protein in the food. The digestible fat and carbohydrates of the food are used for the production of energy and for fat storage. The two principal constituents stored in the body are protein and fat. Any animal fed for the purpose of food production is valuable in the proportion in which it stores protein and fat relative to the amount of carbohydrates, protein, and fat consumed.

The figures giving the total thermal value of the feeds consumed in the different rations during the feeding trial, as well as the total thermal value of the protein and fat stored, are shown in Table XX. The thermal value of the ration was calculated by multiplying the pounds of carbohydrates and protein consumed by 1.8 and the pounds of ether extract by 4.05, assuming that the energy value of these constituents is equal to 1,800 calories per pound of carbohydrates and protein and 4,050 calories per pound of ether extract. For the constituents stored the figures 1.86 and 4.2 were used for the respective constituents. The ratio was calculated by dividing the therms stored into the therms consumed. The graphic representation of these various values is shown in figure 18.

TABLE XX.—*Relation between therms consumed and therms stored*

Experiment No.	Ration.	Therms stored.	Therms consumed.	Ratio.
III	Corn and protein-free skim milk	−26.82	176.43	Loss.
III	Corn and ash	−13.23	250.13	Loss.
VI	Corn alone	−1.23	223.83	Loss.
VI	Corn and ash	6.96	212.92	30.64 : 1
V	Corn alone	101.94	448.75	4.40 : 1
III	do	29.88	389.98	13.06 : 1
VI	Corn and ash-free blood protein	114.26	426.51	3.73 : 1
IV	Corn and ash	120.53	535.81	4.45 : 1
IV	Corn alone	176.31	707.47	4.07 : 1
II	Corn and ash	181.87	700.57	3.85 : 1
II	Corn alone	231.10	826.90	3.58 : 1
IV	Corn and protein-free skim milk	241.78	735.47	3.04 : 1
V	Corn and corn germ	241.91	812.98	3.36 : 1
VI	Corn, starch, casein, and ash	281.62	825.07	2.93 : 1
V	Corn and casein every seventh day	294.37	922.34	3.13 : 1
VI	Corn, ash-free blood protein, and ash	296.05	752.61	2.54 : 1
VI	Corn and casein 1 : 1½ and ash	372.54	932.27	2.50 : 1
VI	Corn, casein 1 : 3, and ash	381.52	1,020.66	2.68 : 1
IV	Corn and albumin	391.20	1,012.09	2.59 : 1
VI	Corn, casein, reducing, and ash	397.14	980.02	2.47 : 1
V	Corn and casein	444.61	1,200.27	2.70 : 1
IV	Corn and milk protein every seventh day	469.41	1,140.43	2.43 : 1
V	Corn and albumin	518.97	1,387.45	2.67 : 1
IV	Corn and casein	581.96	1,558.12	2.68 : 1
III	Corn and milk protein	710.02	1,746.15	2.46 : 1
III–V	Corn and protein-free skim milk	871.00	3,766.56	4.32 : 1
II	Corn and black-blood albumen	908.02	2,307.81	2.54 : 1
III–V	Corn and synthetic ash	911.57	3,457.76	3.79 : 1
II	Corn, black-blood albumen, and ash	970.14	2,569.86	2.65 : 1

CORN WITHOUT ADDITIONAL PROTEIN [1]

The pigs fed on corn alone or on corn and ash or on corn and protein-free skim milk stored less therms on the average in proportion to the thermal value of the feeds consumed than did the pigs to whose ration protein from animal sources was added. The average ration for all the pigs which had corn and had no protein from other sources was nearly 1 to 4.

[1] The five pigs which made a very small gain are not included in discussion.

That is, for four therms consumed in the ration only one was stored in the form of protein or fat. The two continuation pigs stored energy in as efficient a ratio as the younger hogs. Since these two pigs did not make material gains for the first year of the experiment, it means that they must have stored energy in a more efficient ratio during the last year.

CORN WITH ADDITIONAL PROTEIN [1]

The ratio for the pig fed corn and corn germ was 1 to 3.36. This was wider than for any of the pigs fed additional protein, but narrower than for any pig fed corn alone. For the pig fed casein every seventh day the ratio was 1 to 3.13—wider than for any other pig fed protein from milk in addition to corn. For the pig fed milk protein every seventh day the ratio was 1 to 2.43. This was the narrowest ratio for any pig. For the two pigs fed milk protein in medium amounts, one corn and casein 1 to 1.5 and the other corn and casein, reducing, the ratios were 1 to 2.50 and 1 to 2.47, respectively, or narrower than for any of the pigs fed milk protein in the larger amounts. The average ratio for the four pigs fed milk protein in large amounts was 1 to 2.63. From the standpoint of energy storage this larger feeding of milk protein was not as efficient as the smaller feeding of milk protein. The ratio for the pig fed corn, starch, casein, and ash was 1 to 2.93. This was wider than for any pig fed milk protein in addition to corn, except one fed casein every seventh day. For the two pigs fed black-blood albumen the ratio was 1 to 2.58. In this case the ash had no influence. With the ash-free blood protein the addition of ash was a distinct advantage. Without the ash the ratio was 1 to 4.32, as wide as for corn alone. With ash the ratio was 1 to 2.54, as narrow as when large amounts of milk protein were fed.

This analysis shows that feeding corn alone is not advantageous from the standpoint of energy stored. It also shows the distinct advantage of adding a small amount of protein from other sources. The pigs to whose ration from one-tenth to one-third of the total protein in the ration was from milk stored energy in as large a ratio as those whose ration contained over half the protein from milk or from other animal sources.

CONCLUSIONS

PROTEIN STORAGE

1. Pigs fed on corn alone store on the average 1 pound of protein for 7.5 pounds of protein consumed, provided that before the pigs are put on the ration they have attained a certain development.

2. When corn was supplemented with small amounts of protein from milk, from one-eighth to one-tenth of the total protein in the ration, the pigs stored 1 pound of protein for 5.11 pounds consumed.

[1] The five pigs which made a very small gain are not included in the discussion.

3. When corn was supplemented with a medium amount of protein from milk, amounting to nearly one-third of the total protein in the ration, the pigs stored 1 pound of protein for 3.5 pounds consumed.

4. When corn was supplemented with a large amount of protein from milk, from one-half to almost two-thirds of the total protein in the ration, the pigs stored on the average 1 pound of protein for 6 pounds consumed. The amount of protein stored varied from one-fourth to one-half the amount in the milk proteins consumed.

5. A large amount of protein from other sources than corn produces a more rapid rate of gain, but at the expense of the efficiency of protein storage.

6. The most efficient ration from the standpoint of protein storage is one which contains a small amount of protein from milk so combined with other feeds as to make a wide nutritive ratio.

ASH, FAT, AND PROTEIN STORAGE

7. When corn was fed alone the sum of ash, fat, and body protein stored was 1.1 pounds for each pound of protein consumed.

8. When corn was supplemented with a small amount of protein from milk, the sum of ash, fat, and body protein stored was 1.46 pounds for each pound of protein consumed.

9. When corn was supplemented with a medium amount of protein from milk the sum of ash, fat, and body protein stored was 1.41 pounds for each pound of protein consumed.

10. When corn was supplemented with a large amount of protein from milk or other animal proteins the sum of ash, fat, and body protein stored was less than 1.1 pounds for each pound of protein consumed, a less efficient storage of nutrients than when corn was fed alone. This statement leaves rate of growth out of consideration.

11. Feeds combined so as to make a wide nutritive ratio produced the largest amount of storage of ash, fat, and body protein in relation to the amount of protein in the feed.

FAT STORAGE

12. Nine of the 24 pigs studied in these experiments stored more than 1 pound of fat for each pound of protein consumed. Among these 9 the 4 which stored fat in largest amount in proportion to the amount of protein consumed were fed rations having a wide nutritive ratio.

13. Most of the 24 pigs studied in these experiments stored 0.8 pound to 1 pound of fat for each pound of protein consumed. The source of protein did not seem to have any distinct influence. The protein from black blood albumen was as efficient for fat storage as the protein from milk. The 2 pigs fed till they were nearly 3 years old, and whose sole source of protein was corn, stored fat as efficiently in proportion to the amount of protein consumed as the younger pigs which received protein from other sources than corn.

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ENERGY STORAGE

14. Pigs whose sole source of protein was corn stored less therms on the average in proportion to the thermal value of the feeds consumed than did the pigs to whose ration protein from animal sources was added.

15. From the standpoint of energy storage the small amounts of milk protein were as efficient as the larger amounts, but not more so.

16. From the standpoint of energy storage the feeding of corn alone is not efficient. The addition of a small amount of protein from other sources from one-tenth to one-third of the total is as efficient as when one-half or more of the protein comes from other sources.

IV. EFFECT OF PROLONGED FEEDING OF CORN ALONE, CORN AND ASH, OR CORN AND PROTEIN-FREE SKIM MILK ON THE GROWTH AND DEVELOPMENT OF PIGS

That corn alone, corn and ash, or corn and protein-free skim milk is deficient as a ration for young growing pigs has been shown in section III. In experiment II of the series of experiments from which these data have been taken, one of the pigs fed corn alone was continued on this feed for 1,060 days, counting from the beginning of the experiment. This pig was 4 ½ months old at the beginning of the trial, and weighed 54 pounds. In experiment III of this same series, one pig from the lot fed corn and ash and one from the lot fed corn and protein-free skim milk were continued on through for 900 days, counting from the beginning of the experiment. These two pigs were 3½ months old at the beginning of the experiment. The pig fed corn and ash weighed 42 pounds and the pig fed corn and protein-free skim milk weighed 47 pounds at the beginning of the experiment. These ages and weights are important because if these pigs had been younger at the beginning of the trial the results might have been different.

GAIN IN LIVE WEIGHT

The live weight of these pigs at 100-day periods, the gain for these periods, and the corn consumed are given in Table XXI.

The pig fed corn and ash did not make constant gains until 400 days after the beginning of the experiment. The total gain in the first 400 days of the experiment was only 18 pounds, and this was all gained in the first 200 days. This net gain of 18 pounds was at the expense of consuming 361.3 pounds of corn, or 20 pounds consumed for 1 pound of gain. During the last 523 days of the trial the gain was 334 pounds and the corn consumed was 1,646 pounds, or 1 pound gain for 5 pounds consumed. The period of greatest increase was from the seven hundredth to the nine hundredth day. In this time the consumption was 944 pounds and the gain 215 pounds, or 1 pound gain for 4.4 pounds consumed.

TABLE XXI.—*Live weight, gain, and total feed consumed, by 100-day periods*

PIG FED CORN AND ASH

Period.	Weight.	Gain.	Total corn consumed.
	Days.	*Pounds.*	*Pounds.*	*Pounds.*
0 to 100 [a]	56	14	121. 50
100 to 200	65	9	69. 70
200 to 300	53	−12	72. 40
300 to 400	60	7	97. 70
400 to 500	87	27	143. 45
500 to 600	131	44	236. 00
600 to 700	168	37	228. 00
700 to 800	269	101	383. 80
800 to 900	383	114	560. 60
900 to 923	394	7	112. 05
Total			2, 007. 20

PIG FED CORN AND PROTEIN-FREE SKIM MILK

0 to 100 [b]	51	4	81. 45
100 to 200	56	5	78. 30
200 to 300	54	−2	82. 00
300 to 400	64	10	104. 60
400 to 500	89	25	149. 05
500 to 600	132	43	224. 60
600 to 700	202	60	220. 00
700 to 800	293	91	409. 00
800 to 900	379	86	425. 65
900 to 923	375	−4	121. 40

PIG FED CORN ALONE

0 to 100 [c]	58	4	93. 99
100 to 200	68	10	111. 47
200 to 300	82	14	121. 00
300 to 400	128	36	201. 40
400 to 500	134	6	239. 10
500 to 600	135	1	192. 00
600 to 700	180	45	200. 00
700 to 800	243	63	329. 90
800 to 900	370	127	548. 80
900 to 1,000	481	111	676. 00
1,000–1,060	596	115	386. 00

[a] In the 3½ months before the experiment began the pig attained a weight of 42 pounds.
[b] In the 3½ months before the experiment began the pig attained a weight of 47 pounds.
[c] In the 4¼ months before the experiment began the pig attained a weight of 54 pounds.

The pig fed corn and protein-free skim milk gained 17 pounds in the first 400 days of the trial and consumed 346 pounds of corn, or 20 pounds for each pound gain. In the last 523 days of the trial he gained 311 pounds and consumed 1,552 pounds of corn, 5 pounds for each pound of gain.

This pig also made his most rapid gains in the last 200 days, gaining 177 pounds. In this time he consumed 834 pounds of corn and made

1 pound gain for 4.7 pounds consumed. The corn and protein-free skim milk ration had no advantage over the corn and ash ration. The pig fed corn alone did not make steady and constant gains till after the six hundredth day of the trial. He had gained in this time 81 pounds and consumed 959 pounds of corn, or 1 pound of gain for 11.8 pounds con-

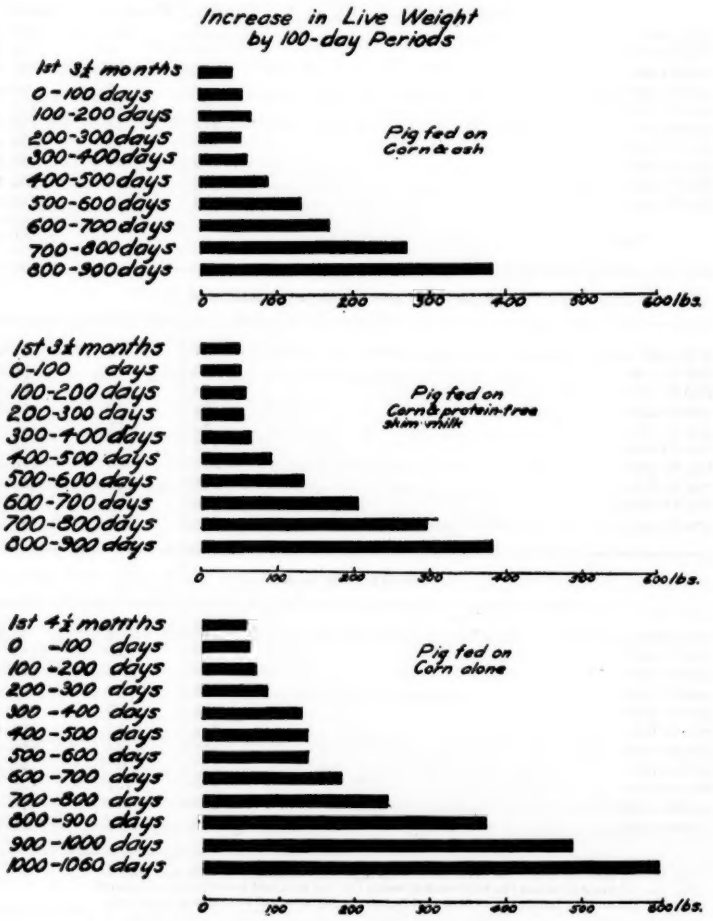

FIG. 19.—Graphical representation of the increase in live weight by 100-day periods.

sumed. This is a better record than for the other two pigs. This gain took place mostly in the first 400 days. In this time the gain was 74 pounds and the consumption was 428 pounds, or 1 pound of gain for 5.7 pounds consumed. There was a period from the four hundredth to the six hundredth day that there was very little gain. In the last 460

days the gain was 461 pounds and the corn consumed was 2,141 pounds, or 1 pound of gain for 4.6 pounds consumed. In the last period of his life the pig fed corn alone made as good gains as the pig fed corn and ash or corn and protein-free skim milk. The facts presented above are graphically shown in figure 19.

The outstanding fact is that in all these pigs there was a long period in which the gains were very small, and after this period the rate of gain and the gain for the amount consumed was equal to that of pigs fed a standard ration. It evidently means that before a pig can make satisfactory gains it must attain a certain development. When corn alone is the sole diet this development is attained very slowly. When alfalfa pasture was the sole source of food, this development took place more rapidly, although the pigs did not gain much in weight. This fact was illustrated by some pigs in this series of experiments which were fed on alfalfa pasture alone. One lot of those pigs gained an average of only 3 pounds each in 120 days. When they were put on corn alone they gained 67 pounds in as many days. This gain was produced from 284 pounds of corn, or 4¼ pounds of corn for each pound of gain. One pig from this lot was analyzed when taken off the alfalfa pasture. Compared with a control pig killed at the beginning of the experiment, he had gained 11.66 pounds moisture, 0.77 pound ash, 2.93 pounds protein, but lost 14.84 pounds fat. Unfortunately no pig from this lot was slaughtered at the end of the trial. But, as has been shown in section I, it is safe to compare pigs of approximately equal size for the purpose of calculating chemical composition. A comparison of the pig of this lot fed corn alone after alfalfa pasture with a slaughtered pig fed corn alone, showed that the following average pounds of gain were made on corn alone in 67 days: moisture, 11.73; ash, 0.87; protein, 3.88; fat, 56.71. While the gains on alfalfa pasture were unsatisfactory, the pigs had attained a certain development of body which gave them vigor to make rapid gains when put on corn alone. It should be noted that the gains were comparatively large in protein and ash on alfalfa pasture, and on corn alone the gain was largely fat. Alfalfa alone is strong in those growth-producing properties in which corn is weak. Corn is strong in fat-producing properties in which alfalfa is weak. Hughes (*6*) has shown that when chickens are fed on corn alone, the growth curve is similar to the one made by pigs fed on corn alone. He also shows that the rate of growth in chickens can be increased by forced feeding.

NUTRIENTS AND THERMS IN CORN CONSUMED

The average composition of corn fed these pigs was assumed to be the same as the average of the corn used in all these experiments—namely, protein, 9.65 per cent; carbohydrates, 75 per cent; fat, 3.8 per cent. In

making calculations for thermal value, 1,800 calories were used for each pound of carbohydrate and protein and 4,060 calories for each pound of fat. On the basis of these figures of thermal value, composition, and the amount of corn consumed in the different 100-day periods, the total therms in corn consumed were calculated. The small thermal value in the organic matter of the protein-free skim milk was omitted from these figures. The figures as obtained are found in Table XXII. The chief value of these figures is to obtain data to use in calculations given further on.

TABLE XXII.—*Weight of nutrients and therms in corn consumed*

PIG FED CORN AND ASH

Period.	Total corn consumed.	Carbohydrates in corn.	Therms in carbohydrates.	Fat in corn.	Therms in fat.	Protein in corn.	Therms in protein.	Total therms in corn.
Days.	*Pounds.*	*Pounds.*		*Pounds.*		*Pounds.*		
0 to 100 [a]	121. 50	91. 13	164. 03	4. 62	18. 76	11. 72	21. 10	213. 89
100 to 200	69. 70	52. 28	94. 10	2. 65	10. 75	6. 73	12. 11	116. 96
200 to 300	72. 40	54. 30	97. 74	2. 75	11. 17	6. 99	12. 58	121. 49
300 to 400	97. 70	73. 28	131. 90	3. 71	15. 06	9. 43	16. 97	163. 93
400 to 500	143. 45	107. 59	193. 66	5. 45	22. 12	13. 84	24. 91	240. 69
500 to 600	236. 00	177. 00	318. 60	8. 97	36. 41	22. 77	40. 99	396. 00
600 to 700	228. 00	171. 00	307. 80	8. 66	35. 16	22. 00	39. 60	382. 56
700 to 800	383. 80	287. 85	518. 13	14. 58	59. 19	37. 04	66. 67	643. 99
800 to 900	560. 60	420. 45	756. 81	21. 30	86. 48	54. 10	97. 38	940. 67
900 to 923	112. 05	84. 04	151. 27	4. 26	17. 30	10. 81	19. 46	188. 03
Total	2, 007. 20					195. 43		

PIG FED CORN AND PROTEIN-FREE SKIM MILK

0 to 100 [a]	81. 45	61. 09	109. 96	3. 10	12. 59	7. 86	14. 15	136. 70
100 to 200	78. 30	58. 73	105. 71	2. 98	12. 10	7. 56	13. 61	131. 42
200 to 300	82. 00	61. 50	110. 70	3. 12	12. 67	7. 91	14. 24	137. 61
300 to 400	104. 60	78. 45	141. 21	3. 97	16. 12	10. 09	18. 16	175. 49
400 to 500	149. 05	111. 79	201. 22	5. 66	22. 98	14. 38	25. 88	250. 08
500 to 600	224. 60	168. 45	303. 21	8. 53	34. 63	21. 67	39. 01	376. 85
600 to 700	220. 00	165. 00	297. 00	8. 36	33. 94	21. 23	38. 21	369. 15
700 to 800	409. 00	306. 75	552. 15	15. 54	63. 09	39. 47	71. 05	686. 29
800 to 900	425. 65	319. 24	574. 63	16. 17	65. 65	41. 08	73. 94	714. 22
900 to 923	121. 40	91. 05	163. 89	4. 61	18. 72	11. 72	21. 10	203. 71
Total	1, 898. 05					182. 97		

PIG FED CORN ALONE

0 to 100 [b]	93. 99	70. 49	126. 88	3. 57	14. 49	9. 07	16. 33	157. 70
100 to 200	111. 47	83. 60	150. 48	4. 24	17. 21	10. 75	19. 35	187. 04
200 to 300	121. 00	90. 75	163. 35	4. 60	18. 68	11. 68	21. 02	203. 05
300 to 400	201. 40	151. 05	271. 89	7. 65	31. 06	19. 44	34. 99	337. 94
400 to 500	239. 10	179. 33	322. 79	9. 09	36. 91	23. 07	41. 53	401. 23
500 to 600	192. 00	144. 00	259. 20	7. 30	29. 63	18. 53	33. 35	322. 18
600 to 700	200. 00	150. 00	270. 00	7. 60	30. 86	19. 30	34. 74	335. 60
700 to 800	329. 90	247. 43	445. 37	13. 54	50. 91	31. 84	57. 31	553. 59
800 to 900	548. 80	411. 60	740. 88	20. 85	84. 65	52. 96	95. 33	920. 86
900 to 1,000	676. 00	507. 00	912. 60	25. 69	104. 30	65. 23	117. 41	1, 134. 31
1, 000 to 1,060	386. 00	289. 50	521. 10	14. 67	59. 56	37. 25	67. 05	647. 71
Total	3, 099. 66					299. 12		

[a] No data for 3½ months preceding experiment.
[b] No data for 4½ months preceding experiment.

TABLE XXIII.—*Protein stored and thermal value*

PIG FED CORN AND ASH

Period.	Live weight.	Percentage of protein.	Total protein in body.	Protein stored.	Therms in protein stored.
Days.	*Pounds.*		*Pounds.*	*Pounds.*	
0 to 100 [a]	56	11	6.16	1.54	2.86
100 to 200	65	11	7.15	.99	1.84
200 to 300	53	11	5.83	−1.32	−2.46
300 to 400	60	11	6.60	.77	1.43
400 to 500	87	11	9.57	2.97	5.52
500 to 600	131	10	13.10	3.53	6.57
600 to 700	168	10	16.80	3.70	6.88
700 to 800	269	9	24.21	7.41	14.15
800 to 900	383	9	34.47	10.26	18.17
900 to 923	394	9	35.46	.99	1.84
Total				32.16	

PIG FED CORN AND PROTEIN-FREE SKIM MILK

0 to 100 [b]	51	11	5.61	0.44	0.81
100 to 200	56	11	6.16	.55	1.02
200 to 300	54	11	5.94	−.22	−.41
300 to 400	64	11	7.04	1.10	2.05
400 to 500	89	11	9.79	2.75	5.12
500 to 600	132	10	13.20	3.41	6.34
600 to 700	202	10	20.20	7.00	13.02
700 to 800	293	9	26.37	6.17	11.48
800 to 900	379	9	34.11	7.74	7.05
900 to 923	375	9	33.75	−.36	−.67
Total				28.16	

PIG FED CORN ALONE

0 to 100 [c]	58	11	6.38	0.44	0.82
100 to 200	68	11	7.48	1.10	1.05
200 to 300	82	11	9.02	1.54	2.86
300 to 400	128	10	12.80	3.78	7.03
400 to 500	134	10	13.40	.60	1.12
500 to 600	135	10	13.50	.10	.19
600 to 700	180	10	18.00	4.50	8.37
700 to 800	243	9	21.87	3.87	7.20
800 to 900	370	9	33.30	11.43	21.26
900 to 1,000	481	9	43.29	9.99	18.58
1,000 to 1,060	596	9	53.64	10.35	19.25
Total				47.70	

[a] In the 3¼ months before the experiment began the pig attained a weight of 42 pounds, of which 11 per cent was protein. The total protein in the body was 4.62 pounds.

[b] In the 3½ months before the experiment began the pig attained a weight of 47 pounds, of which 11 per cent was protein. The total protein in the body was 5.17 pounds.

[c] In the 4½ months before the experiment began the pig attained a weight of 54 pounds, of which 11 per cent was protein. The total protein in the body was 5.94 pounds.

PROTEIN STORAGE

In calculations of the pounds of protein stored in the body it was assumed that the percentage of protein on the basis of live weight was 11 for weights less than 100 pounds, 10 for weights between 100 and 200 pounds, and 9 for weights above 200 pounds. These assumptions are based on average composition of pigs of similar weights. As the last period, 900 to 923 days, for two of the pigs is very short, the figures for this period should not be averaged or considered of any great significance. For calculating the thermal value of the protein stored, 1,860 calories per pound were used. This is not the total thermal value of the protein, but the thermal value of protein used as food. The figures as obtained are given in Table XXIII. They show that in the first 400 days of the experiment about 2 pounds of protein were stored by the corn and ash pig and 1.87 pounds by the corn and protein-free skim milk pig. In the period between 200 to 300 days the figures show a loss of protein. In this time there was a loss in live weight. As this loss was probably mostly fat, the figures for protein storage are no doubt low. The only value of these figures is the contrast between the low gains made in the first 400 days of the experiment and those made in the last half.

The increase in protein content in these pigs is shown graphically in figure 20.

FAT STORED

In the calculation of the amount of fat stored in the body it was assumed that the percentage of fat on the basis of live weight was gradually increasing from 20 to 52 and 55 in the largest pig. This assumption is based on the average composition of pigs of similar size. The two pigs, one fed corn and ash the other fed corn and protein-free skim milk, were slaughtered, so the percentage for fat for the last period is that actually found. The pig fed corn alone was not slaughtered, and the figures were assumed. The figures for the last period of 23 days should be omitted for two of the pigs. In the calculation of the thermal value of the fat stored, 4,200 calories per pound of fat were used.

According to these figures the pig fed corn and ash stored only 9 pounds of fat during the first 400 days and the pig fed corn and protein-free skim milk stored 7 pounds. These figures are probably low.

The increase in fat storage by periods is graphically represented in figure 21. This serves to show the very large increase in fat during the later periods.

RELATION BETWEEN VALUES OF FOOD CONSUMED AND NUTRIENTS STORED

The pounds of protein stored divided into the pounds of protein consumed gives a ratio which serves to show, in a measure, the efficiency of the ration for storage of protein. In section III it has been shown that

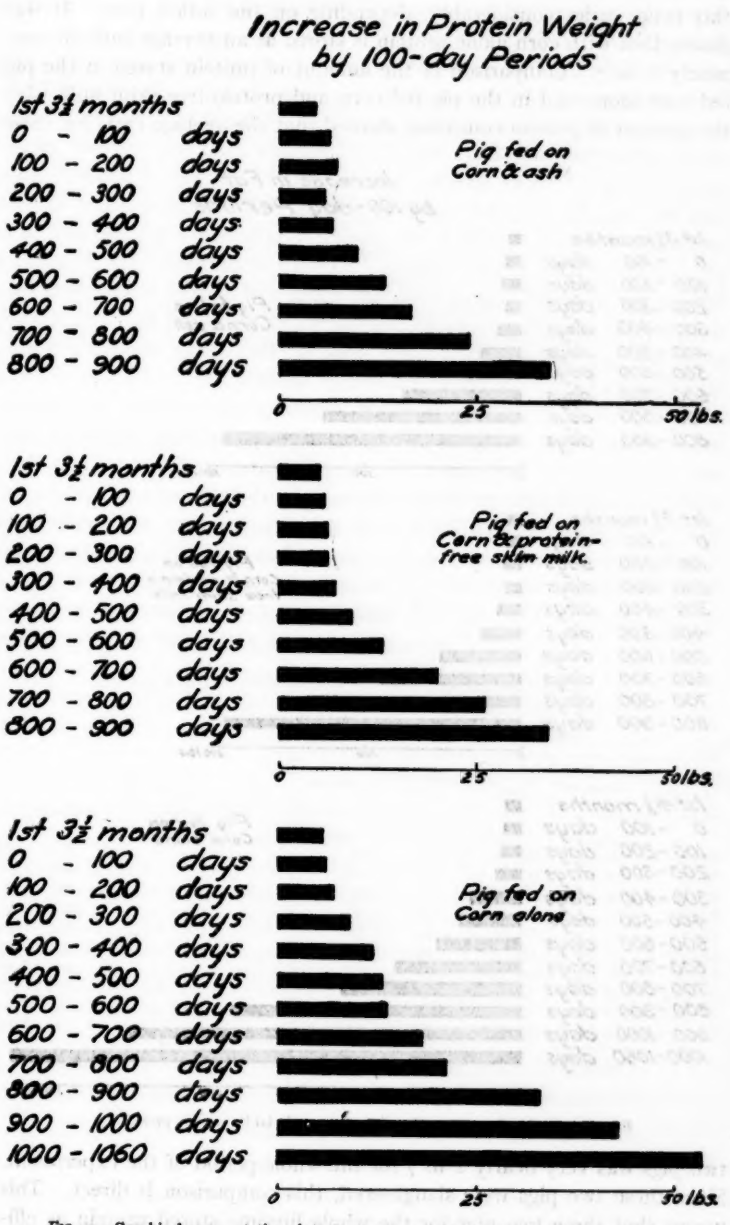

FIG. 20.—Graphical representation of the increase in weight of protein by 100-day periods.

this ratio varies considerably, depending on the ration used. It was shown that with corn alone protein is stored at an average ratio of very nearly 1 to 7. Comparison of the amount of protein stored in the pig fed corn alone and in the pig fed corn and protein-free skim milk with the amount of protein consumed showed that the average ratio for these

FIG. 21.—Graphical representation of the increase in fat by 100-day periods.

two pigs was very nearly 1 to 7 for the whole period of the experiment. Since these two pigs were slaughtered, this comparison is direct. This means that these two pigs for the whole lifetime stored protein as efficiently as those younger pigs which were fed on corn alone but grew more at an earlier stage. Since all these three pigs did not grow much

the first 400 days of the experiment, it means that the protein was stored at a much wider ratio than 1 to 7 during this period. The detailed figures for the calculations by periods are found in Table XXIV. By dividing the calculated amount of protein stored into the amount consumed, we find that the ratio for the pig fed corn and ash was 1 to 17.61 during the first 400 days and for the pig fed corn and protein-free skim milk, it was 1 to 18.88. And for the pig fed corn alone it was 1 to 12.24 for the first 600 days. This narrow ratio for this pig is due to the fact that this pig had a period of relatively rapid growth between the three hundredth and four hundredth day. During the rest of the life of these pigs they stored protein in a much narrower ratio. The average for the pig fed corn and ash was 5.37 for the last 500 days. For the pig fed corn and protein-free skim milk it was 5.96, and for the pig fed corn alone it was 5.15. While these figures are based on several assumptions founded on experimental evidence, it brings out this fact, that the best ratio in which protein was stored by these pigs fed corn was not far from 1 to 5. While this ratio is narrower than that obtained from pigs fed protein in abundance from other sources than corn, it is much wider than when corn was supplemented by a small amount of protein. The ratio for the pig fed corn and casein, reducing (see section III), was 1 to 3.7, the one fed corn and casein from 1½ pounds of milk for each pound of corn was 1 to 3.3, and that for the one fed corn, starch, casein, and ash was 1 to 2.9.

TABLE XXIV.—*Pounds of fat stored and thermal value*

PIG FED CORN AND ASH

Period.	Weight.	Percentage of fat.	Total fat in body.	Fat stored.	Therms in fat stored.
Days.	*Pounds.*		*Pounds.*	*Pounds.*	
0 to 100 [a]	56	20	11.20	2.80	11.76
100 to 200	65	20	13.00	1.80	7.56
200 to 300	53	20	10.60	−2.40	−10.08
300 to 400	60	25	15.00	4.40	18.48
400 to 500	87	30	26.10	11.10	46.62
500 to 600	131	40	52.40	26.30	110.46
600 to 700	168	45	75.60	23.20	97.44
700 to 800	269	47	126.43	50.83	213.49
800 to 900	383	50	191.50	65.07	273.29
900 to 923	394	52.5	206.85	15.35	64.47
Total				200.85	

TABLE XXIV.—*Pounds of fat stored and thermal value*—Continued

PIG FED CORN AND PROTEIN-FREE SKIM MILK

Period.	Weight.	Percentage of fat.	Total fat in body.	Fat stored.	Therms in fat stored.
Days.	*Pounds.*		*Pounds.*	*Pounds.*	
0 to 100 [b]	51	20	10.20	0.80	3.36
100 to 200	56	20	11.20	1.00	4.20
200 to 300	54	20	10.80	−.40	−1.68
300 to 400	64	25	16.00	5.20	21.84
400 to 500	89	30	26.70	10.70	44.94
500 to 600	132	40	52.80	26.10	109.62
600 to 700	202	45	90.90	38.10	160.02
700 to 800	293	47	137.71	46.81	196.60
800 to 900	379	50	189.50	51.79	217.52
900 to 923	375	52	195.00	5.50	23.10
Total				186.00	

PIG FED CORN ALONE

0 to 100 [c]	58	20	11.60	0.80	3.36
100 to 200	68	20	13.60	2.0	8.40
200 to 300	82	20	16.40	2.80	11.76
300 to 400	128	25	32.00	15.60	65.52
400 to 500	134	30	40.20	8.20	34.44
500 to 600	135	40	54.00	13.80	57.96
600 to 700	180	45	81.00	27.00	113.40
700 to 800	243	47	114.21	33.21	139.48
800 to 900	370	50	185.00	70.79	297.32
900 to 1,000	481	52	250.12	65.12	273.50
1,000 to 1,060	596	55	327.80	77.68	326.26
Total				317.00	

[a] In the 3 1/2 months before the experiment began the pig attained a weight of 42 pounds, of which 20 per cent was fat. The total fat in the body was 8.40 pounds.
[b] In the 3 1/2 months before the experiment began the pig attained a weight of 47 pounds, of which 20 per cent was fat. The total fat in the body was 9.40 pounds.
[c] In the 4 1/2 months before the experiment began the pig attained a weight of 54 pounds, of which 20 per cent was fat. The total fat in the body was 10.80 pounds.

RELATION BETWEEN TOTAL THERMS CONSUMED AND TOTAL THERMS STORED

The pig fed corn and ash consumed 19.31 therms for one stored during the first 400 days of the experiment. During the last 500 days of the experiment he consumed 3.28 therms for one stored. The pig fed corn and protein-free skim milk consumed 18.33 therms for one stored during 400 days of the experiment and 3.11 for one stored during the last 500 days of the experiment. For the pig fed corn alone the therms consumed were 8.23 for the first 600 days and 2.93 for the last 400 days for each therm stored. (Table XXV.)

In section III it was shown that pigs fed corn alone stored on the average 1 therm for 4 consumed. This was with pigs which made some growth on corn alone. In pigs that made a small growth or none at all, the ratio

was much wider. The two pigs compare, in the first 400 days, with those that made a very small growth on corn alone. The pig fed corn alone stored energy a little more efficiently the first 600 days. During the last period of the experiments these pigs compare with the pig fed corn, starch, casein, and ash and the pig fed corn and casein from 3 pounds of milk every seventh day. But when the energy storage is compared with that of the pigs fed corn and medium amounts of milk protein, the ratio is wider. This means that even in the last stages of growth when the increase in live weight was rapid and the gain in proportion to the amount of corn consumed was satisfactory, the energy storage was not as good as with the pigs fed a moderate amount of protein from sources other than corn.

The graphic presentation of the relation between therms consumed and therms stored are given in figure 22.

TABLE XXV.—*Summary of pounds of protein consumed and pounds of protein stored, therms in nutrients consumed and therms in nutrients stored, and ratios*

PIG FED CORN AND ASH

Period.	Protein consumed.	Protein stored.	Ratio.	Average ratio.	Therms in nutrients consumed.	Therms in nutrients stored.	Ratio.	Average ratio.
Days.	*Pounds.*	*Pounds.*						
0 to 100[a]	11.72	1.54			203.89	14.62	13.94	
100 to 200	6.73	.99		17.61	116.96	9.40	12.33	19.31
200 to 300	6.99	— 1.32			121.49	—12.54	Loss.	
300 to 400	9.43	.77			163.93	19.91	8.23	
400 to 500	13.84	2.97	4.66		240.69	52.14	4.61	
500 to 600	22.77	3.53	6.45		396.00	117.03	3.38	
600 to 700	22.00	3.70	5.95	5.37	382.56	104.32	3.67	3.28
700 to 800	37.04	7.41	5.00		643.99	227.64	2.83	
800 to 900	54.10	10.26	5.27		940.67	292.00	3.22	

PIG FED CORN AND PROTEIN-FREE SKIM MILK

0 to 100[a]	7.86	0.44			136.70	4.17	32.78	
100 to 200	7.56	.55		18.88	131.42	5.22	25.17	18.33
200 to 300	7.91	— .22			137.61	— 2.09	Loss.	
300 to 400	10.09	1.10			175.49	23.89	7.34	
400 to 500	14.38	2.75	5.23		250.08	50.06	4.99	
500 to 600	21.67	3.41	6.36		376.85	115.96	3.25	
600 to 700	21.23	7.00	3.03	5.96	369.15	173.04	2.13	3.11
700 to 800	39.47	6.17	6.40		686.29	208.08	3.30	
800 to 900	41.08	3.79	10.84		714.22	224.57	3.18	

PIG FED CORN ALONE

0 to 100[b]	9.07	0.44			157.70	4.18	37.72	
100 to 200	10.75	1.10			187.04	10.45	17.90	
200 to 300	11.68	1.54		12.24	203.05	14.62	13.89	8.23
300 to 400	19.44	3.78			337.94	72.55	4.66	
400 to 500	23.07	.60			401.23	35.56	11.28	
500 to 600	18.53	.10			322.18	58.15	5.54	
600 to 700	19.30	4.50	4.29		335.60	121.77	2.76	
700 to 800	31.84	3.87	8.22		553.59	146.68	3.77	
800 to 900	52.96	11.43	4.63	5.15	920.86	318.58	2.89	2.93
900 to 1,000	65.23	9.99	6.53		1,134.31	292.08	3.88	
1,000 to 1,060	37.25	10.35	3.60		647.71	345.51	1.87	

[a] No data for 3½ months preceding experiment.
[b] No data for 4½ months preceding experiment.

CONCLUSIONS

1. Two pigs, one put on a ration of corn and ash, one on a ration of corn and protein-free skim milk when 3½ months old, did not make satisfactory gains until they had been on this ration for about 500 days.

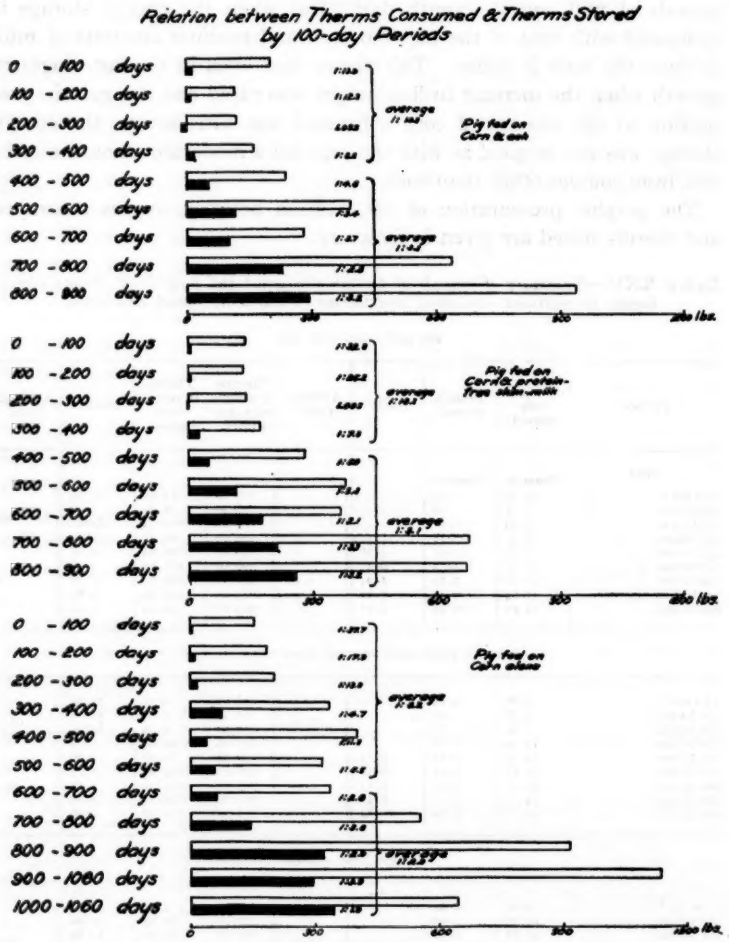
Relation between Therms Consumed & Therms Stored by 100-day Periods
0 - 100 days
100 - 200 days
200 - 300 days
300 - 400 days
400 - 500 days
500 - 600 days
600 - 700 days
700 - 800 days
800 - 900 days
average
Pig fed on Corn & ash
0 - 100 days
100 - 200 days
200 - 300 days
300 - 400 days
400 - 500 days
500 - 600 days
600 - 700 days
700 - 800 days
800 - 900 days
average
Pig fed on Corn & protein-free skim-milk
0 - 100 days
100 - 200 days
200 - 300 days
300 - 400 days
400 - 500 days
500 - 600 days
600 - 700 days
700 - 800 days
800 - 900 days
900 - 1000 days
1000 - 1060 days
average
Pig fed on Corn alone

FIG. 22.—Graphical representation of the relation between therms consumed and therms stored by 100-day periods.

From that time for 400 days they made good gains. One other pig put on a ration of corn alone when 4½ months old made very slow gains for about 300 days, more rapid gains the following 400 days, and for the last 360 days of the experiment he made rapid gains.

2. When corn was the sole source of protein in the ration, the ratio of protein stored to protein consumed was 1 to 7. This ratio was obtained when corn was fed for a prolonged period—900 days. This agrees with the ratio obtained in several other instances when corn was fed for a period of 180 days. This appears to be the limit of the possibilities of protein storage from corn.

3. The two pigs, one fed corn and ash, the other fed corn and protien-free skim milk, stored 1 therm for 18.82 consumed during the first 400 days of the experiment. During the last 500 days they stored 1 therm for 3.19 consumed. The pig fed corn alone stored 1 therm for 8.23 consumed during the first 600 days. During the last 400 days he stored 1 therm for 2.93 consumed.

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SOME FUNDAMENTALS OF STABLE VENTILATION

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COOPERATIVE INVESTIGATIONS BETWEEN THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE AND THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE

Much study has been given in the past to the mechanical aspects of stable ventilation and to the construction of efficient systems; but, so far as the authors are aware, singularly little attention has been paid to the amount of motive power available for the operation of these systems. This is particularly true of that portion of it which is derived from the heat production of the animals, notwithstanding the fact that the latter may vary within wide limits and may at times constitute the sole motive power.

In the cooperative investigations upon animal nutrition which have been carried on at this institute during the past 20 years, a large number of direct determinations of the heat production of cattle under different conditions have been made. Numerous similar determinations have also been made by Kellner (*11*, *12*, *13*)[1] by the method of indirect calorimetry. A smaller number of results upon other species of farm animals are also on record. Upon the initiative and with the efficient cooperation of Mr. W. B. Clarkson, chairman of the Committee on Farm Building Ventilation of the American Society of Agricultural Engineers, we have attempted to work out a method by which these results may be applied to the problems of stable ventilation and the heat production in any specific case computed with a fair approximation to accuracy. The present paper contains the results of these endeavors.

INTRODUCTION

The installation of an effective ventilating system must necessarily depend, first, on a knowledge of the scientific principles involved and, second, upon a study of the conditions of each individual case. As the amounts of pure air required by the different species of farm animals are different, the minimum volume of air movement through a stable must vary accordingly. The construction of a ventilating system must be based on the unit of air movement chosen and on the available motive power which is to ensure the required supply of air.

[1] Reference is made by number (italic) to "Literature cited," p. 367-368

Journal of Agricultural Research, Washington, D. C.
XX
Vol. XXI, No. 5
June 1, 1921
Key No. Pa.-11
42269°—21——5

The motive power utilized in stable ventilation is chiefly the passing wind and the heat and water vapor given off by the animals. It frequently happens, however, that the motive force due to the wind is very small or even zero. At such times the air movement is entirely dependent upon the motive power derived from a rise in temperature and from an increase in the moisture content of the air after it enters the stable. It is therefore important to know this minimum motive power—that is, the heat and water vapor supplied by the animals, as this knowledge is evidently fundamental in determining the proper dimensions of the ventilating system.

But the heat given off by farm animals, while serving as a motive power for ventilation, is also relied upon to maintain the temperature of the stable at a comfortable degree in cold weather. The Committee on Farm Building Ventilation of the American Society of Agricultural Engineers in its recent report (*8*) to the society has emphasized very strongly the need of effective control of the temperature in farm buildings, as based on a number of its investigations. The committee found many barns with well-equipped ventilating systems which were not producing satisfactory results to the owners, not because of inadequate ventilation, but because of the fact that the buildings were too cold. All these facts point to the necessity of knowing how much heat is given off by the different farm animals and is available for heating and ventilating purposes.

Besides heat and water vapor farm animals give off carbon dioxid and some volatile organic products. Air once respired contains carbon dioxid in a quantity which makes it unfit to be breathed again unless very much diluted with pure air. It is chiefly the carbon-dioxid content of the air that serves as a basis for determining its degree of purity. In selecting a unit of air movement in the construction of a ventilating system it appears, therefore, that a knowledge of the average amounts of carbon dioxid produced by the different animals must be of not a little significance.

AMOUNT OF AIR REQUIRED FOR DIFFERENT SPECIES AND STANDARD OF PURITY

From what has just been said it is clear that the question of stable ventilation is a question of maintaining the proper purity of air in the stable as well as the proper temperature. Air supports the life of the animal. The air an animal breathes is as much an indispensable part of the feed it consumes as is the hay or the grain eaten. Within the animal body neither assimilation of food nor generation of energy can take place without the consumption of a proportionate amount of air. When the animals are outside they have plenty of pure air at their disposal; in the stable, however, the air is contaminated with the gases thrown off by them. Unless there is an air movement at a proper rate into and

out of the stable, these gases—the carbon dioxid and the volatile organic products exhaled by the animals—will accumulate and may have injurious effects on them.

King (*14*) bases his estimates of the volume of air which should move continuously through stables, first, on the amount of pure air which must be breathed by different animals and, second, on the standard of purity recommended by him. According to his computations a horse must draw into and force out of his lungs, on the average, each hour, some 142 cubic feet of air, the cow 117, the pig 46, and the sheep 30 cubic feet.

The standard recommended by King requires a degree of purity of air not lower than 96.7 per cent.—that is, that the air in the stable shall at no time contain more than 3.3 per cent of air once breathed. Since the air coming from the lungs contains about 4.24 volume per cent of carbon dioxid and pure air 0.028 volume per cent, it appears that King's standard allows $4.24 \times 0.033 + 0.028 \times 0.967$, or 0.167 volume per cent of carbon dioxid. From the amounts of air breathed by the different animals given above, the rate at which air must enter and leave the stable to correspond to this standard is computed per hour and per head as follows:

For horses: $\frac{142 \times 100}{3.3} = 4{,}303$ cubic feet.

For cows: $\frac{117 \times 100}{3.3} = 3{,}545$ cubic feet.

For swine: $\frac{46 \times 100}{3.3} = 1{,}394$ cubic feet.

For sheep: $\frac{30 \times 100}{3.3} = 909$ cubic feet.

It is not claimed that the standard of air purity and the units of air movement for the different animals given above are absolutely needed. While they probably afford a good gauge by which to be guided, they have been given here mainly to illustrate the method and the basis of their computation.

MOTIVE POWER FOR STABLE VENTILATION

The maintenance of a flow of air through a building requires the continuous expenditure of energy, and the amount of this energy and the work done will be in direct proportion to the weight of air moved through the ventilated space and the resistance it is necessary to overcome in accomplishing this movement. To supply air to 100 horses, for example, at the rate of 4,303 cubic feet per hour and per head, the necessary amount of work is that of moving through the stable each hour $\frac{4{,}303 \times 0.08 \times 100}{2{,}000}$ or 17.2 tons, 0.08 representing the weight of 1 cubic foot of air in pounds.

The power used to accomplish the air movement through stables, as already stated, is chiefly the passing wind and the heat and moisture given off by the animals. The motive force due to the wind depends on its velocity, direction, etc., and is, in general, very variable and sometimes

even zero. On the other hand, the amounts of heat and water vapor given off by animals are fairly constant under like conditions and must, therefore, be depended upon to cause a flow of air sufficient to supply the minimum amount needed. Since it is this minimum air movement that concerns us most, only the motive power derived from the heat and water vapor produced by the animals will be considered here.

ANIMAL HEAT AS A MOTIVE POWER IN VENTILATION

The immediate cause of air movement into and out of a ventilated space is a difference of pressure established between the air in the space to be ventilated and that outside. The effect of the heat given off by the animals is to render the air of the stable relatively lighter than the air outside. This difference in density causes a difference in pressure, which tends to maintain a continuous flow of air into and out of the stable.

The difference in pressure between the air in the barn and that outside resulting from a difference in temperature can be computed in the following way: When air is warmed its volume expands 1/491 of its volume at 32° F. for each degree Fahrenheit rise in temperature. This expansion tends to force out 1 cubic foot of air for each 491 cubic feet contained in the stable, and the air remaining will consequently weigh less than an equal volume outside by an amount equal to the weight of the air thus forced out. If, for example, in a stable containing 19,640 cubic feet, or one very nearly 40 by 40 by 12.3 feet, the temperature is raised to 57°, as compared with 32° outside, the air forced out by expansion will be $\frac{19,640 \times 25}{491}$, or 1,000 cubic feet. In other words, the air remaining will weigh 80 pounds less than an equal volume outside. This means that the total pressure into the stable at the floor is 80 pounds greater than that exerted outward by the inside air; and, since the floor has an area of $40 \times 40 = 1,600$ square feet, the pressure tending to force air into the stable at a floor opening and out at the ceiling is $\frac{80}{1,600}$, or 0.05 pound per square foot.

Based on the foregoing considerations, the magnitude of the temperature effect in producing draft, according to King, is represented by the following equation:

$$\text{Cubic feet per hour} = 60 \times 60 \times 8\sqrt{\frac{T-t}{491}}H,$$

in which—

60×60 is the number of seconds per hour,
8 is $\sqrt{2g}$, g being the value of gravity, 32.16 feet per second,
T is the temperature of air inside,
t is the temperature of air outside,
H is the height of room or ventilator,
1/491 is the expansion of air for 1° F.

This equation gives the theoretical value of the air flow per square foot of cross section. The actual flow of air is, however, less than the theoretical, its relative value depending on the resistance which the moving air has to overcome. It appears from an examination of the equation that in order to determine the flow of air the height and the cross section of the ventilator and the difference in temperature between the inside and outside air must be known. On the other hand, from the unit of air movement chosen and the difference in temperature likely to exist the minimum size of the ventilator can be determined.

What difference in temperature can be maintained by the heat given off by the different animals when the ventilation is sufficient to supply the minimum amount of air needed is a question which will be considered later in its relation to heat emission.

WATER VAPOR AS A MOTIVE POWER IN VENTILATION

The water vapor which the animals give off is under ordinary conditions taken up by the moving air and carried off as rapidly as it is formed. The addition of the water vapor to the air in the stable tends to make it lighter than that outside, and this effect serves as a measure of the influence of water vapor as a motive power in ventilation.

The higher the temperature of the air the greater is its moisture-holding capacity. The more moisture the air contains the lighter it is. Consequently, the motive power derived from the water vapor is greater the higher the temperature of the stable air and the more completely it is saturated.

The quantities of water vapor produced by the different animals are given later. The motive power derived from the moisture is much less than that derived from the heat; and, since its magnitude largely depends on the difference in temperature, it can be considered only as secondary in importance.

PRINCIPLES INVOLVED IN THE PRODUCTION OF HEAT BY ANIMALS

The function of the animal heat as a motive power for stable ventilation has already been considered. A second function of the animal heat is to keep the stable warm in cold weather. The optimum temperature to be maintained in the stable varies with the kind of animal and also with the ration. There exists also a certain relation between the heat given off by the animal and its thermal surroundings. For the purpose of estimating approximately the best stable temperature, both as regards comfort and economy, it appears desirable to turn to a consideration of the scientific principles involved.

REGULATION OF BODY TEMPERATURE

Farm animals belong to that general class known as warm-blooded animals, whose bodies during health maintain a nearly constant temperature which is the resultant of two factors, thermogenesis, or the

development of heat inside the body, and thermolysis, the loss of heat from the body, principally by radiation and conduction and as latent heat of water vapor. The external temperature tends to influence the outflow of heat, but the animal is able to regulate it by physical and chemical methods.

There is a certain external temperature, called the critical temperature, at which the outflow of heat just balances the necessary heat production of the animal as a result of internal work. Above this temperature the radiating capacity of the body surface is varied to meet the varying conditions; below it, this method of regulation is largely exhausted, and therefore more or less oxidation of tissue is required to maintain the normal temperature of the body.

EFFECT OF FEED CONSUMPTION ON THE HEAT PRODUCTION AND ON THE CRITICAL TEMPERATURE

It is a fact demonstrated by numerous experiments that the consumption of feed results in increasing the heat production of an animal. When an animal is fasting it produces a certain amount of heat due to the vital functions of the internal organs. This is generally termed basal, or fasting katabolism. When the animal is fed, its heat production is increased over that of the fasting state. This increment of heat brought about by the consumption of feed has been ascribed to various causes, one of which is the expenditure of energy in the digestion and assimilation of the feed, often collectively termed "work of digestion."

The more heat the animal produces the more cold it naturally can withstand without being compelled to oxidize body tissue in order to maintain the normal body temperature. This, in other words, means that the consumption of feed lowers the critical temperature, the effect varying with the nature and quantity of the feed. Animals fed heavily, as in productive feeding, can therefore withstand more cold, or have a lower critical temperature, than animals kept on a simple maintenance ration, while the critical temperature of the latter is higher than that of the fasting animal.

EFFECT OF LOW THERMAL SURROUNDINGS ON MAINTENANCE REQUIREMENT

From what has just been said it appears that a ration sufficient for maintenance at a temperature higher than the critical may be insufficient for maintenance when the thermal surroundings are lower than the critical, because of the failure to meet the demand for heat. What the critical temperatures of the different farm animals are is therefore a question not only of physiological but also of economic significance.

It is apparent, however, that the critical temperatures of farm animals do not lend themselves to accurate determination. At best they are estimated only approximately. A summary of the results of different

investigators on this subject (*3, p. 312*) shows that the critical external temperature for the horse is high as compared with that of ruminants, so that a ration which is sufficient for maintenance in summer may be insufficient in winter. The critical temperature for swine has been likewise found to be comparatively high (68° to 73° F.), which means that exposure to low temperatures may be expected to increase the actual maintenance ration and the heat production of swine, and this has been confirmed by experimental results. On the other hand, the results on cattle seem to indicate that their critical temperature is rather low (much below 56°), which means that cattle can be exposed to lower temperatures than horses or swine before their maintenance requirement will be affected and their heat production stimulated.

EFFECT OF LOW THERMAL SURROUNDINGS ON PRODUCTIVE FEEDING

The production of meat or milk implies the consumption of large quantities of feed. Since the latter is the source of a large amount of heat, due to the "work of digestion," which has to be removed at a correspondingly rapid rate, it appears that heavy producers are better adapted to relatively cold thermal surroundings. Furthermore, since it is the aim in feeding such animals to induce them to eat as much feed as can be economically converted into useful products, it seems desirable, on the one hand, that the thermal surroundings should be low in order to maintain the appetite of the animals and, on the other, not so low as would cause wasteful oxidation for simple heat production.

The question whether winter feeding for fattening can be accomplished to better advantage in the stable than in the open shed has interested many investigators, and a considerable amount of experimental work is on record. The results (1) show in general that cattle are best adapted to exposure—that is, they produce as good results when exposed as when stable fed. Swine are least adapted to exposure, the gain of the animals exposed to severe weather being frequently negative, while sheep seem to take an intermediate place. These results are in full harmony with the findings given above as regards the critical temperature. Less decisive results have been obtained with dairy cows, but it appears fairly well established that for well-fed animals the need for warm stables has been somewhat overemphasized.

OPTIMUM STABLE TEMPERATURE

Both theoretical considerations and the results of experience show that a certain excess of heat production over that absolutely required to maintain the body temperature is likely to be advantageous, both by promoting the comfort of the animal and as providing a margin of safety. On the other hand, an unnecessarily high temperature tends to affect the appetite and general health of the animal. From this it follows that the best thermal surroundings for animals lie between these limits—

namely, somewhat above the critical point, but not so much as to affect the appetite and thrift. These limits, evidently, will vary with the species of animal and with the amount and character of the ration. The best temperature surroundings for animals being fed high, according to King, are likely to lie between 45° and 50° F., while for animals on a maintenance ration, the best temperatures may be between 55° and 65°. For dairy cows having large udders only scantily clothed with hair and through which much blood must flow, a temperature as high as 50° to 60° is considered as probably the best.

Whether the heat eliminated by animals is sufficient to maintain in the stable approximately these temperatures in cold weather when the air movement is at the proper rate will be considered on subsequent pages.

METHOD OF COMPUTING HEAT PRODUCTION

The discussions of the foregoing paragraphs make it evident that the heat produced by an animal may be regarded as the sum of two factors, first the necessary internal work due to the vital activities of the internal organs and, second, the "work of digestion." The first gives rise to an amount of heat equivalent to the fasting katabolism, which varies with the species and size of the animal, while the second gives rise to an increment of heat due to feed consumption, which varies with the character and quantity of the ration. It is clear, then, that no single standard value can be assumed as representing even approximately the heat production of any species.

When the fasting katabolism of an animal and the heat increment due to the feed eaten are known, it is evident that the total heat produced by the animal can be computed by simple addition. Experimental data are available from which it is possible to estimate more or less accurately the fasting katabolism of farm animals according to their live weights, and also the increment of heat due to the ration feed. These data have been used as the general basis for computing the heat production. The details of the method are best illustrated by the computation on subsequent pages of the heat production of dairy cows.

ACCURACY OF THE COMPUTATIONS

The reader should beware of being led by the apparently very exact figures of the tables on succeeding pages to ascribe to these data a greater degree of accuracy than they really possess.

In the first place they represent specific cases assumed to be more or less typical. The actual production of heat, carbon dioxid, and water by a given species will show wide variations from stable to stable, and in the same stable from time to time, according to the size of the animals, their degree of activity, and especially the amounts of feed which they consume.

In the second place, it is by no means intended to assert on page 354, for example, that every Jersey cow weighing 750 pounds and yielding 20 pounds of 5 per cent milk will produce exactly 16,313 calories of total heat. The computations have been made on the basis of average results from which those on an individual animal may vary considerably. This is especially true of the fasting katabolism. Moreover, the computations have been carried out to the nearest whole calorie so as to record the exact results of the calculation. In view, however, of the many possibilities of experimental error involved, it seems very questionable whether the last three digits are significant. Probably an estimate to the nearest thousand calories—that is, to one therm—would be all that is justified and would be sufficiently accurate for the discussion of all ventilation problems.

HEAT PRODUCTION OF CATTLE

FASTING KATABOLISM

The data for the fasting katabolism of cattle, although obtained by indirect methods and not by actually starving the animals, are more trustworthy than those for any other species of farm animals for the reason that they are more abundant, are concordant, and are based largely on experiments with the respiration calorimeter by means of which direct determinations of the heat production were made. In these experiments the animal is usually fed two different amounts of the same feed, and the effect of this on the heat production—that is, the decrease of heat production per pound decrease of feed—is determined. From this it is estimated how much heat would be produced if all the feed were withdrawn—that is, if the animal were reduced to the fasting state.

The average given by Armsby (*3, p. 711*) for the fasting katabolism of cattle per 1,000 pounds live weight is 6 therms, or 6,000 calories, and, as the fasting katabolism of animals of the same species has been found to be approximately proportional to the two-thirds power of their live weight, that of cattle is computed accordingly. Table I gives the fasting katabolism of cattle according to their live weight in terms of calories.

TABLE I.—*Fasting katabolism of cattle*

Live weight.	Calories, per head.	Live weight.	Calories, per head.
150	1,690	1,000	6,000
250	2,380	1,250	6,960
500	3,780	1,500	7,860
750	4,950		

HEAT INCREMENT DUE TO THE CONSUMPTION OF FEED BY CATTLE

The energy expended by cattle in the increased body activities connected with the digestion and assimilation of many feeding stuffs have been determined directly by varying the amount of the feeding stuff in

the ration and by determining the heat production. From a comparison of two determinations the heat increment caused by a pound of feeding stuff can be determined. The data for the heat increment caused by different feeding stuffs are average figures computed by Armsby and Fries (*4, 5*) from the results of their own experiments and those of Kellner and Köhler (*11, 12, 13*) on beef cattle and are given in Table II in calories per pound of dry matter. The corresponding figures for dairy cows would probably be somewhat less, but how much less has not yet been determined.

TABLE II.—*Increment of heat production by cattle per pound of dry matter consumed*

Feeding stuffs.	Experimenters.	Energy expenditure.
		Calories.
Roughage:		
Timothy hay	Armsby and Fries	354.7
Red clover hay	do	441.3
Do	Kellner and Köhler	422.7
Mixed hay	Armsby and Fries	444.5
Alfalfa hay	do	530.3
"Grass hay"	Kellner and Köhler	474.0
Meadow hay	do	568.8
Rowen	do	434.6
Corn stover	Armsby and Fries	483.1
Barley straw	Kellner and Köhler	397.8
Oat straw	do	460.0
Wheat straw	do	516.2
Straw pulp	do	526.2
Concentrates:		
Corn meal	Armsby and Fries	583.3
Hominy chop	do	619.2
Wheat bran	do	533.9
Cottonseed meal	Kellner and Köhler	443.6
Linseed meal	do	547.9
Palmnut meal	do	456.8
Peanut meal	do	525.7
Beet molasses	do	448.2
Starch	do	566.1
Peanut oil	do	783.4
Wheat gluten	do	950.8

In its relations to stable ventilation the computation of the heat production of cattle is of special interest in the case of dairy cows, since in cold climates these animals are almost always stabled during the winter while beef cattle are quite commonly fed in the open. The computations for cows are therefore given in considerable detail in the following paragraphs.

TYPICAL WEIGHTS AND RATIONS OF DAIRY COWS

Obviously, no single value can be given for the heat production of the dairy cow, since it varies widely according to the size of the animal and the amount of feed consumed. All that is possible is to select certain typical live weights and rations and to compute the corresponding heat production as illustrations of the method in its application to specific

cases, such as may be found in good practice. The typical weights and rations upon which the computation of the heat emission by dairy cows has been based are those suggested, at the request of Mr. Clarkson, by Prof. C. H. Eckles, of the University of Minnesota.

TABLE III.—*Typical live weights and rations*

Breed.	Live weight.	Daily milk yield.		Daily ration.			
		Pounds.	Percentage of fat.	Corn silage.	Alfalfa hay.	Grain mixture.[a]	Additional linseed meal.
	Pounds.			*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Jersey	900	20	5.0	30	8	6	.....
Do	900	30	5.0	30	8	9	1
Holstein	1,250	30	3.5	40	10	6	.....
Do	1,250	45	3.5	40	10	10	1

[a] Composed of ground corn 4 parts, wheat bran 2 parts, linseed meal 1 part.

COMPUTATION OF THE HEAT PRODUCTION OF DAIRY COWS

To compute, for example, the daily heat production by the typical Jersey cow giving 20 pounds of milk daily, it is only necessary to add to the fasting katabolism of a cow weighing 900 pounds the heat increment due to the ration consumed. According to Table I the fasting katabolism of a cow weighing 1,000 pounds is 6,000 calories, while that for one weighing 750 pounds is 4,950 calories. From these figures the fasting katabolism of a cow weighing 900 pounds may be estimated with sufficient accuracy by simple proportion as being 5,580 calories per day.

It remains to figure out the heat increment caused by the consumption of feed. By using the average percentages of dry matter in the feeds as given in Henry and Morrison's tables (*10*) it is found that the amounts of dry matter contained in the ration are:

In corn silage ..... 7.9 pounds.
In alfalfa hay ..... 7.3 pounds.
In grain mixture ..... 5.4 pounds.

Since the grain mixture consists of 4 parts of corn, 2 parts of wheat bran, and 1 part of linseed meal, the heat increment per pound of dry matter of the grain mixture (Table II) is:

$$1/7(583.3\times4+533.9\times2+547.9\times1)=564.1 \text{ calories.}$$

The heat increment per pound of dry matter of alfalfa hay is 530.3 calories, and that of corn silage is assumed to be 483.1 calories—that is, the figure corresponding to corn stover—since no figure for corn silage is available. From these figures the total heat increment caused by the ration is obtained as follows:

Corn silage	483.1	× 7.9 =	3,816 calories.
Alfalfa hay	530.3	× 7.3 =	3,871 calories.
Grain mixture	564.1	× 5.4 =	3,046 calories.
Total heat increment			10,733 calories.

Adding to this the fasting katabolism of the Jersey cow, 5,580 calories, gives the total heat production per day as 16,313 calories.

Computed by this method, the total heat production by the cows per day per head is shown in Table IV.

TABLE IV.—*Total heat production by typical cows per day per head*

Animal.	Calories.
Jersey cow producing 20 pounds of milk	16,313
Jersey cow producing 30 pounds of milk	18,273
Holstein cow producing 30 pounds of milk	19,905
Holstein cow producing 45 pounds of milk	22,372

HEAT GIVEN OFF BY RADIATION AND CONDUCTION AND AS LATENT HEAT OF WATER VAPOR

The heat emission as computed above includes that given off by radiation and conduction and the latent heat of the water vaporized. The latent heat of water vapor, however, can hardly be regarded as available for ventilation purposes, inasmuch as under average conditions there is no considerable accumulation of condensed water, the water vapor being removed from the barn as rapidly as it is produced by the animals so that there is little chance for its latent heat to be liberated.

From the experiments on cattle with the respiration calorimeter it has been found that except on very heavy rations the latent heat of water vapor constitutes approximately 25 per cent of the total heat given off, while about 75 per cent is eliminated by radiation and conduction. On this basis, the heat emission by radiation and conduction and as latent heat of water vapor per day per head for cows has been computed (Table V).

TABLE V.—*Heat given off by radiation and conduction and as latent heat of water vapor per day per head by typical cows*

Animal.	Heat emission by radiation and conduction.	Latent heat of water vapor.
	Calories.	*Calories.*
Jersey cow producing 20 pounds of milk	12,235	4,078
Jersey cow producing 30 pounds of milk	13,705	4,568
Holstein cow producing 30 pounds of milk	14,929	4,976
Holstein cow producing 45 pounds of milk	16,779	5,593

WATER VAPOR PRODUCED BY COWS

The computation of the amount of water vapor produced by an animal when the latent heat of the water vapor is known is a very simple matter. The latent heat of 1 gm. of water vapor is 0.587 calorie. By

dividing, therefore, the calories of latent heat of water vapor by 0.587 the number of grams of water vapor produced is obtained. In the foregoing cases the computed amounts per day and per head are as shown in Table VI.

TABLE VI.—*Water vapor produced by typical cows per day and per head*

Animal.	Water vapor.
	Gm.
Jersey cow producing 20 pounds of milk	6,947
Jersey cow producing 30 pounds of milk	7,782
Holstein cow producing 30 pounds of milk	8,477
Holstein cow producing 45 pounds of milk	9,528

CARBON DIOXID PRODUCED BY COWS

Since carbon dioxid is a product of combustion, however slow it may be, within the animal body, it is natural to expect that a more or less definite relation between the heat production and the output of carbon dioxid must exist. From the accumulated data of the heat emission and carbon dioxid production by cattle determined directly by means of the respiration calorimeter at this Institute, the relation of the carbon dioxid produced to the heat given off has been very recently established by Armsby, Fries, and Braman (*6*), who, on comparing the daily output of carbon dioxid and the heat production by steers and cows for 188 separate days, found that in each case the ratio of the carbon dioxid produced in grams to the total heat emission in calories was very close to 1 to 2.5, or 0.4, the mean ratio being 1 to 2.495. By making use of this factor the amount of carbon dioxid produced by cows in grams is computed by simply multiplying the calories of daily heat emission by 0.4.

TABLE VII.—*Carbon dioxid produced by cows per day and per head*

Animal.	Carbon dioxid.
	Gm.
Jersey cow producing 20 pounds of milk	6,525
Jersey cow producing 30 pounds of milk	7,309
Holstein cow producing 30 pounds of milk	7,962
Holstein cow producing 45 pounds of milk	8,949

HEAT PRODUCTION OF COWS ON MAINTENANCE

The daily maintenance ration of cattle has been computed by Armsby (*2*) from a number of experiments in terms of metabolizable energy, which in this case also represents the total heat production, 10,500 calories being the average per 1,000 pounds live weight. This, com-

puted in proportion to the two-thirds power of the live weight, gives 9,788 and 12,184 calories, respectively, as the daily total heat production on maintenance by the Jersey and Holstein cows of the assumed weights. The heat emission by radiation and conduction, the water vapor, and the carbon dioxid produced by cows on maintenance have been computed by the methods just described and are included in the summary of the results of the computations on dairy cows in Table VIII.

TABLE VIII.—*Heat, water vapor, and carbon dioxid produced by typical cows per day and per head*

Animal.	Total heat emission.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Water vapor.	Carbon dioxid.
	Calories.	*Calories.*	*Calories.*	*Gm.*	*Gm.*
Jersey cow producing 20 pounds of milk	16,313	12,235	4,078	6,947	6,525
Jersey cow producing 30 pounds of milk	18,273	13,705	4,568	7,782	7,309
Holstein cow producing 30 pounds of milk	19,905	14,929	4,976	8,477	7,962
Holstein cow producing 45 pounds of milk	22,372	16,779	5,593	9,528	8,949
Jersey cow on maintenance	9,788	7,341	2,447	4,169	3,915
Holstein cow on maintenance	12,184	9,138	3,046	5,189	4,874

HEAT PRODUCTION OF HORSES

HEAT INCREMENT DUE TO THE CONSUMPTION OF FEED

While the general principles of the computation of the fasting katabolism of horses are essentially the same as for cattle, the computation of the heat increment due to the consumption of feed is a much more complicated process. The reason for this lies in the fact that no calorimetric experiments for the direct determination of the heat production and of the balance of energy have been made with horses, and consequently an indirect method of computation of the heat increment has to be resorted to, which involves many estimates and calculations.

From the results of their experiments, Zuntz and Hagemann (*18*) estimate that the metabolizable energy of the feed of a horse equals 1,796 calories per pound of digestible nutrients; and they assume, on the basis of Magnus Levy's experiments on man, that 9 per cent of the metabolizable energy of the digestible nutrients consumed by a horse is converted into heat in the process of digestion. They furthermore compute from the results of their own experiments that each pound of total crude fiber consumed increases the heat production by 1,202 calories additional, so that the total heat increment due to consumption of feed by the horse is the sum of these two amounts. It is obvious that this method of computation necessitates a knowledge of the digestibility and of the total crude fiber content of the feed.

To illustrate the method of computing the heat increment due to the consumption of feed, that caused by a pound of oats is calculated as follows, the digestible nutrients being those given in Bulletin 186 of the Kansas Experiment Station (*15*), with the exception of those for clover hay, which are taken from Henry and Morrison's tables (*10*), from which have also been obtained the data for total crude fiber.

Digestible nutrients of oats

Protein	0.107 pound.
Carbohydrates	0.503 pound.
Fat (3.8×2.4)	0.092 pound.
Total	0.702 pound.
Total crude fiber	0.109 pound.
Metabolizable energy	1,796 calories×0.702=1,260.8 calories.

Heat increment

9 per cent metabolizable energy	1,260.8×0.09 =113.5 calories.
Additional for crude fiber	1,202 ×0.109=131.0 calories.
Total heat increment	244.5 calories.

The heat increment caused by other feeding stuffs has been computed in a similar manner.

FASTING KATABOLISM

The total heat production of the horse was estimated by Zuntz and Hagemann (*18*) from the respiratory exchange determined by means of a respiration apparatus for short periods after the consumption of different rations. From a comparison of the results and by the indirect method of computing the heat increment due to the work of digestion which has been illustrated they have computed the average fasting katabolism of the horse to be 4,100 calories per 1,000 pounds live weight. In proportion to the two-thirds power of the live weight the fasting katabolism of horses, as computed by Armsby, is given in Table IX.

TABLE IX.—*Fasting katabolism of horses*

Live weight.	Fasting katabolism per head.	Live weight.	Fasting katabolism per head.
	Calories.		*Calories.*
150	1,160	1,000	4,100
250	1,630	1,250	4,760
500	2,580	1,500	5,370
750	3,390		

TYPICAL WEIGHTS AND RATIONS OF HORSES

As examples of typical live weights and rations for horses upon which to base the computation of the heat production of these animals the following, suggested, at the request of Mr. Clarkson, by J. L. Edmonds, of the Illinois College of Agriculture, have been used.

Daily ration for light horses that get only about enough exercise to keep them in good condition per 1,000-pound horse:

8 pounds of oats.
2 pounds of wheat bran.
10 pounds of timothy hay.

Daily ration for 1,500-pound geldings at moderate work:

9 pounds of oats.
9 pounds of ear corn.
7½ pounds of timothy hay.
7½ pounds of clover hay.

TOTAL HEAT PRODUCTION

The total heat increment due to the ration fed, computed in the manner described, plus the fasting katabolism of the horse, gives the total heat production of horses of the weights and consuming the rations just specified when performing no work. The heat production is, of course, greatly increased during work, but plainly this additional heat is not ordinarily available as motive power for ventilation.

TABLE X.—*Total heat production per day and per head by typical horses at rest*

Animal.	Live weight.	Heat.
	Pounds.	*Calories.*
Light horses	1,000	10,853
Heavy work horses	1,500	14,835

HEAT EMISSION BY RADIATION AND CONDUCTION, WATER VAPOR, AND CARBON DIOXID PRODUCED BY HORSES

On the assumption that approximately the same relation exists as in the case of cattle between the total heat emission and the latent heat of water vapor and between the heat and the carbon dioxid produced by horses, a computation was made of the heat given off by radiation and conduction, the latent heat of the water vapor, the amount of water vapor, and the amount of carbon dioxid produced by horses. The method described above for cows was used, and the results are shown in Table XI.

TABLE XI.—*Heat emission by radiation and conduction, water vapor, and carbon dioxid produced per day and per head by typical horses at rest*

Animal.	Live weight.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Amount of water vapor.	Carbon dioxid.
	Pounds.	*Calories.*	*Calories.*	*Gm.*	*Gm.*
Light horses	1,000	8,140	2,713	4,622	4,341
Heavy work horses	1,500	11,126	3,709	6,319	5,934

HEAT PRODUCTION OF SWINE

FASTING KATABOLISM

The fasting katabolism of swine has been determined independently by Meissl (*16*) and by Tangl (*17*) by starving the experimental animals for comparatively short periods and measuring the katabolism by means of a respiration apparatus. The average of their results, computed per 100 pounds in proportion to the two-thirds power of the live weight, is 1,250 calories. The fasting katabolism of swine, computed according to their live weight, is given in Table XII.

TABLE XII.—*Fasting katabolism of swine*

Live weight.	Fasting katabolism per head.	Live weight.	Fasting katabolism per head.
Pounds.	*Calories.*	*Pounds.*	*Calories.*
25	496	300	2,599
50	786	400	3,149
100	1,250	450	3,406
150	1,637	600	4,126
200	1,984		

HEAT INCREMENT DUE TO CONSUMPTION OF FEED BY SWINE

The data regarding the increment of heat production consequent on the consumption of feed by swine are rather meager. Of these, the results of several investigators on grains and on a mixed ration consisting of rice, flesh meal, and whey, as reported by Armsby (*3, p. 656*), are considered trustworthy; and the average of these, 417 calories per pound of dry matter eaten, is taken to represent the energy expenditure by swine.

RATIONS FOR SWINE

The rations and live weights of the animals, upon which the computation of heat emission by swine has been based, are those furnished at the request of Mr. Clarkson, by Prof. J. M. Evvard of Iowa Experiment Station. The weights of the animals and the daily feed eaten, reduced for convenience to dry matter, are the following:

Class.	Weight.	Dry matter of daily feed eaten.
		Pounds.
Suckling pig	25	1.29
Weanling pig	50	2.15
Shote, young	100	3.44
Shote, well-grown	150	6.02
Fattening hog	200	7.74
Farrowing hog	300	6.88
Breeding gilt	300	3.44
Breeding yearling sow	400	4.30
Breeding old sows, year or over	500	5.16
Breeding boar, young	300	3.44
Breeding boar, yearling	450	5.16
Breeding boar, old	600	6.02

TOTAL HEAT PRODUCTION OF SWINE

Since 417 calories represent the increment in heat production by swine per pound of dry matter eaten, the heat increment caused by the consumption of feed by swine is computed on the basis of the foregoing estimates by simple multiplication. To this the fasting katabolism of the animal as found in Table XII is added, and the total heat production is thus obtained (Table XIII).

TABLE XIII.—*Total heat production of typical swine*

Animal.	Live weight.	Total heat emission.
	Pounds.	*Calories.*
Suckling pig	25	1,034
Weanling pig	50	1,684
Shote, young	100	2,684
Shote, well-grown	150	4,147
Fattening hog	200	5,211
Farrowing hog	300	5,468
Breeding gilt	300	4,033
Breeding yearling sow	400	4,942
Breeding old sow	500	5,806
Breeding boar, young	300	4,033
Breeding boar, yearling	450	5,658
Breeding boar, old	600	6,636

HEAT EMISSION BY RADIATION AND CONDUCTION, WATER VAPOR, AND CARBON DIOXID PRODUCED BY SWINE

TABLE XIV.—*Heat emission by radiation and conduction, water vapor, and carbon dioxid produced by typical swine per day and per head*

Animal.	Live weight.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Amount of water vapor.	Carbon dioxid.
	Pounds.	*Calories.*	*Calories.*	*Gm.*	*Gm.*
Suckling pig	25	776	259	441	414
Weanling pig	50	1,263	421	717	674
Shote, young	100	2,013	671	1,143	1,074
Shote, well-grown	150	3,110	1,037	1,767	1,659
Fattening hog	200	3,908	1,303	2,220	2,084
Farrowing hog	300	4,104	1,367	2,329	2,187
Breeding gilt	300	3,025	1,008	1,717	1,613
Breeding yearling sow	400	3,707	1,235	2,104	1,977
Breeding old sow	500	4,355	1,451	2,472	2,322
Breeding boar, young	300	3,025	1,008	1,717	1,613
Breeding boar, yearling	450	4,169	1,389	2,366	2,223
Breeding boar, old	600	4,977	1,659	2,826	2,654

The results of experiments on man (7) indicate that the heat emission by radiation and conduction is on the average not far from 75 per cent of the total heat emission, and that the relation of the carbon dioxid produc-

tion to the total heat production is likewise about the same as in cattle. The apparent agreement of these relationships between two so widely different species leads to the assumption that the results are, at least for this purpose, applicable also to swine. By using, therefore, the method of computation previously described for cattle, the heat emission by radiation and conduction, the latent heat of water vapor, the amount of water vapor, and the amount of carbon dioxid produced by swine are obtained.

HEAT PRODUCTION OF SHEEP

FASTING KATABOLISM

No direct determinations of the fasting katabolism of sheep are on record. From the rather scanty data regarding the maintenance ration of sheep available Armsby (*3, p. 711*) has computed by an indirect method, based on results with cattle, the fasting katabolism of sheep weighing 100 pounds to be 791 calories, and in proportion to the two-thirds power of live weight as given in Table XV.

TABLE XV.—*Fasting katabolism of sheep*

Live weight.	Fasting katabolism per head.	Live weight.	Fasting katabolism per head.
Pounds.	*Calories.*	*Pounds.*	*Calories.*
20	270	120	890
40	430	140	990
60	560	160	1,090
80	680	180	1,170
100	791	200	1,250

HEAT INCREMENT DUE TO CONSUMPTION OF FEED

No determinations of the increment of heat due to the consumption of feed by sheep have been reported, but it appears probable that the results obtained with cattle (Table II) may be applied to sheep without very serious error.

RATIONS FOR SHEEP

The average rations and live weights upon which the computation of the heat emission by sheep is based were taken from several sources. For fattening lambs, the average ration and live weight given by Henry and Morrison (*10, p. 521*) in their summary of the results on sheep of several different experiment stations were used as an example. For breeding ewes, the average ration and live weight given by Hackedorn (*9*) was used. The average ration for maintenance was taken from Bulletin 143 of the Bureau of Animal Industry, United States Department of Agriculture (*2*), the ration being given in terms of metabolizable

energy, which in a maintenance ration also represents the heat production. The respective live weights and rations per head in the two other cases are as follows:

Fattening lambs, average live weight 81.4 pounds—
Shelled corn, 1.3 pounds.
Alfalfa hay, 1.4 pounds.
Breeding ewes, average live weight 90.3 pounds—
Shelled corn, 0.27 pounds.
Wheat bran, 0.14 pounds.
Linseed meal, 0.05 pounds.
Clover hay, 2.08 pounds.
Silage, 2.09 pounds.

TOTAL HEAT PRODUCTION OF SHEEP

By applying to the foregoing rations the estimates and assumptions of the two preceding paragraphs, the total heat emission for sheep may be computed, and from that the heat emission by radiation and conduction, the latent heat of water vapor, the amount of water vapor, and the amount of carbon dioxid produced, exactly as for the other species. The results are as shown in Table XVI.

TABLE XVI.—*Heat emission, water vapor, and carbon dioxid produced by typical sheep per day and per head*

Animal.	Average live weight.	Total heat emission.	Heat emission by radiation and conduction.	Latent heat of water vapor.	Water vapor.	Carbon dioxid.
	Pounds.	*Calories.*	*Calories.*	*Calories.*	*Gm.*	*Gm.*
Fattening lambs.....	81.4	2,044	1,533	511	871	818
Breeding ewes.....	90.3	2,021	1,516	505	860	808
Sheep on maintenance..	100.0	1,483	1,112	371	632	593

VENTILATION AND STABLE TEMPERATURE

The method employed by King to compute the rate of air flow for the different species has been given in an earlier paragraph of this paper. It was also shown that, assuming average figures for the percentage of carbon dioxid in the air coming from the lungs and in pure air, respectively, the air flow thus computed corresponds to 0.167 volume per cent of carbon dioxid in the stable air. Taking 0.167 per cent carbon dioxid as a standard, we have computed Table XVII, showing the rate of air flow that will be required to maintain this standard of purity when based on the average computed carbon-dioxid production by the different species in the examples shown in Tables VII, XI, XIV, and XVI. The last column in the table, giving King's figures for the air flow, has been inserted for the sake of comparison.

TABLE XVII.—*Air flow per head to maintain 0.167 per cent carbon dioxid*

Species.	Carbon dioxid produced per day.		Air flow per day.	Air flow per hour.	Air flow per hour according to King.
	Gm.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
Cows	[a] 7,686	138.348	82,843	3,452	3,545
Horses	5,138	92.484	55,379	2,307	4,303
Swine	1,708	30.744	18,410	767	1,394
Sheep	740	13.320	7,976	332	909

[a] Average carbon-dioxid production by cows in milk.

A glance at the last two columns of Table XVII reveals that while King's air flow for cows agrees fairly well with that computed from the carbon dioxid produced, those for other species differ very widely. In other words, either King's figures for volume of respiration in other species than cattle are too high or his assumption of a uniform percentage of carbon dioxid in the expired air is erroneous. At any rate, the actual carbon-dioxid production would seem to be the proper basis upon which to estimate the rate of ventilation required.

TEMPERATURE DIFFERENCE BETWEEN THE STABLE AND OUTSIDE AIR

As already shown, a considerable part of the motive power for stable ventilation is derived from the heat eliminated by the animals, and this heat is also depended upon to maintain the proper temperature in the stable. Obviously, the difference in temperature that can be maintained between the stable air and that outside depends, other things being equal, upon the balance between heat production and heat loss in ventilation. The maximum value of this difference can be computed, when the rate of the air flow and the heat production values are known, on the assumption that no heat is lost by radiation through the walls of the stable. It should, however, be borne in mind that it is only the heat eliminated by radiation and conduction that should be made the basis of the computation, since the latent heat of water vapor, as already explained, is not available for this purpose.

METHOD OF ESTIMATING THE TEMPERATURE DIFFERENCE

Assuming for the purpose of illustration an air movement corresponding on the one hand to King's standard and on the other hand to the amounts computed in Table XVII from the carbon-dioxid production, the temperature difference that can be maintained by the different animals can be determined in the following manner: One calorie of heat can raise the temperature of a pound of water about 4° F. Since the specific heat of air is 0.237 and since 100 cubic feet of air weigh 8 pounds, one calorie of heat can raise the temperature of 100 cubic feet of air $\frac{4}{0.237 \times 8}$, or 2.1°. Consequently the heat required to warm by 1°

the daily volume of air per head required by King's standard or that computed in Table XVII from the carbon-dioxid production is:

Species.	By King's standard	By our estimates.
	Calories.	*Calories.*
Cows	405	394
Horses	492	264
Swine	159	88
Sheep	104	38

Supposing now that all the heat eliminated by the animals by radiation and conduction is imparted to the air passing into and out of the stable—that is, assuming that no heat is lost by radiation through the walls of the stable—this heat is capable of maintaining a temperature difference in degrees Fahrenheit equal to the daily heat emission per head by radiation and conduction divided by the figures of the foregoing table.

MAXIMUM TEMPERATURE DIFFERENCE MAINTAINED BY THE DIFFERENT SPECIES

By the method just described and by the use of the corresponding heat elimination values a calculation has been made of the maximum average difference in temperature between the stable and the outside air that can be maintained by the animal when King's (*14*) standards for ventilation or those computed from the carbon-dioxid production in Table XVII are used. This calculation is given in Table XVIII.

TABLE XVIII.—*Average temperature difference maintained by animals*

Species.	Average live weight.	Average temperature difference.	
		Corresponding to air flow computed by King.	Corresponding to air flow computed from carbon-dioxid production.
	Pounds.	°*F.*	°*F.*
Cows[a]	1,075	35.6	36.58
Horses	1,250	19.6	36.49
Swine	280	20.0	36.40
Sheep	91	13.3	36.50

[a] The average heat emission by radiation and conduction by cows in milk were used for the computation.

On the basis of the average figures for the temperature difference given above, Table XIX has been computed, showing approximately the temperature of the stable when air enters at different temperatures,

first, at the rate recommended by King, and second, at the rate computed by the writers (Table XVII, columns 6 and 5, respectively).

TABLE XIX.—*Temperature in stable as compared with that outside*

Temperature of outside air.	Temperature of air in stable.				
	Corresponding to King's figures for ventilation.				Corresponding to air flow given in Table XVII, column 5.
	Cow.	Horse.	Swine.	Sheep.	All species.
°F.	°F.	°F.	°F.	°F.	°F.
−20	15.6	−0.4	0.1	−6.7	16.5
−10	25.6	9.6	10.1	3.3	26.5
0	35.6	19.6	20.1	13.3	36.5
10	45.6	29.6	30.1	23.3	46.5
15	50.6	34.6	35.1	28.3	51.5
20	55.6	39.6	40.1	33.3	56.5
25	60.6	44.6	45.1	38.3	61.5
30	65.6	49.6	50.1	43.3	66.5
35	70.6	54.6	55.1	48.3	71.5

This table is interesting in that it shows approximately the point at which the heat supplied by the animals becomes deficient for maintaining the proper temperature in the stable. Thus, when King's standard of air flow is taken as the minimum, the heat supplied by cows appears to become deficient for maintaining what is believed to be the best stable temperature when the outside temperature is below 15° F. The heat supplied by horses, swine, and sheep appears to become deficient at a much higher outside temperature. When, however, the rate of air flow computed from the carbon-dioxid production is made the basis of the computation, the differences between the species disappear.

MAXIMUM VENTILATION TO MAINTAIN A GIVEN TEMPERATURE DIFFERENCE

Conversely, the same data may be used to compute the maximum rate of air flow compatible with the maintenance of a given temperature difference between the stable and the air outside—for example, a stable temperature of 50° F. in zero weather—since it is evident that if the air flow be reduced the temperature difference and consequently the efficiency of the animals to warm the stable will be increased, while if the ventilation be increased the contrary will be the case. To illustrate this point Table XX has been computed, showing what rate of air movement would be required if it were desired to maintain a temperature difference of 50° between the stable and the outside air. It should be noted that, as in Tables XVIII and XIX, these are maximum values, since no allowance is made for losses of heat through the stable walls.

TABLE XX.—*Maximum rate of air flow possible if a temperature difference of 50° F. is to be maintained*

Species.	Average live weight.	Air flow per day per head.	Air flow per hour per head.
	Pounds.	*Cubic feet.*	*Cubic feet.*
Cows	1,075	60,530	2,522
Horses	1,250	40,459	1,686
Swine	280	13,453	561
Sheep	91	5,825	243

The results recorded in Table XX are notably lower than the minimum air flow computed in Table XVII as necessary to maintain the carbon-dioxid content of the stable air at 0.167 per cent and still further below the rate of air flow recommended by King. In other words (at least in the specific cases used as examples) it will be necessary in severe weather to restrict the ventilation in order to conserve heat and maintain a desirable stable temperature, and consequently the stable air will fall below King's standard of purity—namely, 0.167 per cent of carbon dioxid. The writers are not acquainted with any investigations upon the effects of a higher percentage of carbon dioxid upon animals during long periods, but in experiments with the respiration calorimeter this limit has frequently been exceeded in 2-day trials with no obvious ill effects.

Evidently there is a certain degree of discrepancy between King's requirements and the results of our computations. As has been mentioned on previous pages, the amount of carbon dioxid produced by animals is approximately proportional to their heat production, so that the rate of ventilation should also be approximately proportional to the heat production in order to maintain any desired standard or purity in the air of the stable. It is true that the heat production of animals may vary widely, but to the extent to which the examples we have used may be regarded as typical it appears that the accepted ventilation requirements for the different species are not proportional to their heat production. Taking the values for cows as unity, the relative computed heat production and King's relative ventilation requirements are approximately as follows:

Animal.	Relative heat production.	Relative air movement.
Cows	1.0	1.0
Heavy horses	.8	1.2
Swine	.2	.4
Sheep	.1	.3

Too much stress should not be laid on these differences, in view of the paucity of data for other species than cattle, but they indicate clearly the need for further fundamental investigation.

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TREATMENT OF CELERY SEED FOR THE CONTROL OF SEPTORIA BLIGHT[1]

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Septoria blight is often traceable to the use of infected seed. In a study of control measures at this point an obvious line of attack is through seed disinfection. It is a simple matter to kill spores on the surface of the seed by superficial disinfection. However, many infected seeds have spores in pycnidia embedded in the pericarp, and an attempt to kill these with a chemical disinfectant would endanger the vitality of the seed.

Statements from seed dealers and growers that many celery growers use seed 2 or 3 years old suggested the possibility that the spores of Septoria on and in the seed might not remain viable for so long a period. This indicated a second line of attack.

Accordingly, the problem of control was approached along two lines: (*a*) A study of the effect of aging the seed on the vitality of the spores and mycelium of Septoria; (*b*) the use of hot water as a disinfectant. The results are presented in this paper.

EFFECT OF AGING CELERY SEED ON THE VITALITY OF SEPTORIA SPORES

Conidia taken from celery leaves or from the surface of the seed and stored under the usual laboratory conditions were dead in from 8 to 11 months from maturity. Conidia from the peduncles and pericarps of seed gave a 2 to 3 per cent germination at the end of 2 years but were always dead at the end of 3 years. Spores from 1-year-old seed were slightly more viable than those from 2-year-old seed. Germ tubes of spores from 2-year seed were few and slow in developing, 8 days being the minimum time of appearance. Other results indicate that spores dried for 1 or 2 years in the pericarp of seed lack the vigor to produce germ tubes capable of penetrating the tissues of healthy celery plants. It should be stated that the mycelium in the leaves, on the seed, in the seed, and in the peduncles of the seed was dead at or before the time herein reported for the death of the spores. Therefore, no reference has been made to the age at which the mycelium died. The germination tests of conidia and mycelium were conducted in the field during the

[1] Published with the approval of the director, Massachusetts Agricultural Experiment Station.

The writer is indebted to Prof. A. Vincent Osmun, head of the department of botany of the Massachusetts Agricultural Experiment Station, for criticism of the manuscript.

month of September of three different years, so that environmental conditions might be identical with those of the celery fields.

After determining the maximum age at which spores of Septoria retain their vitality, it was necessary to determine also just how long celery seed remains viable. Seeds of different ages were collected from several reliable seed firms (numbered from 1 to 7 in Table I) and tested to determine the percentage of germination. Two hundred seeds of each year represented under each firm were used in making the tests. These tests were repeated three times during the autumn of 1919 in order to verify results. The percentage of germination given in Table I is the average of the three tests.

TABLE I.—*Percentage of germination of celery seed of different ages* [a]

Seed firm.	5 years old.	4 years old.	3 years old.	2 years old.	1 year old.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	6.0	31.6	34.4	34.6	.....
2	.....	.....	.....	.....	50.2 [b] / 47.8
3	.....	35.0	.....	52.0	41.0 [b]
4	11.8	.....	.....	.....	.....
5	.....	32.0	38.8	.....	55.0
6	8.4	35.0	40.2	48.6	.....
7	5.1	40.2	.....	.....	62.5

[a] Blanks indicate that no samples were obtained.

[b] American-grown seed; all other seed French grown.

From Table I it is apparent that celery seed germinates well at from 1 to 4 years of age but that at 5 years the percentage of germination is so reduced that it would be inadvisable to use seed of this age. American-grown celery seed gave a lower percentage of germination than French-grown seed. This explains why in No. 3 the percentage of germination of 1-year-old seed is lower than that for 2-year-old seed. The writer is aware that the percentage of germination of most of the 1-year-old seed presented in Table I is slightly below that of the United States standard of germination (60 to 65 per cent), but since all tests were made under the same conditions the results are relative, and, therefore, admit of comparison.

By purchasing seed 1 or 2 years old and retaining it until it is 3 or 4 years old the grower not only eliminates the fungus but has the opportunity to test the seed for pureness of strain, quality of plant produced, and elimination of seed weak in vitality.

HOT-WATER METHOD OF SEED DISINFECTION

It can be readily seen that any method of surface disinfection is insufficient to destroy the spores embedded in pycnidia in the pericarp of the seed. Other investigators have devised various means of meeting

this problem. Coons and Levin [1] recommend soaking the seed in warm but not hot water for one-half hour and then in a 1 to 1,000 corrosive-sublimate solution for one-half hour. Watts [2] states that some growers disinfect their seed by placing it for a few minutes in a 1 to 32 copper-sulphate solution. The seed should be dried thoroughly after this treatment.

The method devised by the writer is based on tests to determine whether the thermal death point of the fungus is lower than that of celery seed. Thermal exposures (30 minutes was substituted for the usual 10) were made of the pathogene under the following conditions: (a) Spore suspensions in sterile distilled water in test tubes; (b) mycelium 2 weeks old in sterile distilled water in test tubes; (c) nutrient agar cultures 2 weeks old in test tubes. These forms of the fungus were heated in a double boiler for 30 minutes to each degree of temperature between 38° and 55° C. The results showed that only a slight percentage of the spores were viable after being heated to 38° and that none retained viability after exposure at 40°. None of the nutrient agar cultures were viable at 44°, whereas the mycelium in the water blanks was nonviable at 45°. The higher death point of mycelium in the water blanks is probably due to the different densities of the two media.

The method adopted for determining the thermal death point of the seed is as follows: Duplicate lots of 200 seed of Golden Self-blanching celery inclosed in cheesecloth bags were heated in water at 40° C. for 30 minutes, and at each degree between 45° and 50°. Untreated controls for comparison were used in all cases. The results are shown in Table II.

TABLE II.—*Percentage of germination of celery seed heated at various temperatures*

Temperature.	Percentage of germination of seed.	Temperature.	Percentage of germination of seed.
°C.		°C.	
40	49.5	48	44.0
45	51.8	49	40.0
46	43.3	50	32.8
47	44.5	Control.	46.8

In other words, the temperatures of 40° and 45° C. increased germination 5.8 and 10.7 per cent, respectively, over the control, whereas the temperatures from 46° to 49° injured germination slightly. At 50° germination fell 29.9 per cent below the control. The temperature at which celery seed loses its vitality lies somewhere between 50° and 55°. From the foregoing it is evident that heating 1- and 2-year-old celery seed in water at 48° or 49° for 30 minutes eliminates all possibility of Septoria infection of seedlings from such seed.

[1] COONS, G. H., and LEVIN, Ezra. THE SEPTORIA LEAF SPOT DISEASE OF CELERY OR CELERY BLIGHT. Mich. Agr. Exp. Sta. Spec. Bul. 77, 8 p., 9 fig. 1916.

[2] WATTS, Ralph L. VEGETABLE GARDENING. p. 302–326. New York. 1912.

SUMMARY AND CONCLUSIONS

As a rule American-grown celery seed is freer from Septoria spores than French-grown seed.

Spores and mycelium taken from the surface of celery seed or from the pycnidia in celery leaves and kept in the laboratory lose their vitality in 8 to 11 months.

Conidia and mycelium from pycnidia in the peduncles and pericarp of celery seed gave from 2 to 3 per cent germination at the end of 2 years but were dead at the end of 3 years.

The vitality of the conidia and the mycelium which germinate at the end of 1 and 2 years is very low.

Celery seed 3 or 4 years old gave a good germination test. The percentage of germination of seed more than 4 years old is too low to warrant the use of such seed by commercial growers.

The conidia are killed when heated for 30 minutes in water at 40° C.; the mycelium is killed at 45°; celery seed when similarly heated is not appreciably injured below 50°. The vitality of celery seed is destroyed between 50° and 55°.

The vitality of spores and mycelium in the pericarp of celery seed is destroyed at 48° and 49° C. without seriously injuring the germinating power of the seed; higher temperatures greatly impair the power of the seed to germinate.

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